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References

The Journal reference style is the "Vancouver" style, printed in the Medical Journal of Australia, February 15, 1988; 148: 189-194. In this system references appear in the text as superscript numbers.[1,2] The references are numbered in order of quoting. Index Medicus abbreviations for journal names are to be used. Examples of the format for quoting journals and books are given below.

1 Anderson T. RAN medical officers' training in underwater medicine. *SPUMS J* 1985; 15 (2): 19-22
2 Lippmann J and Bugg S. *The diving emergency handbook*. Melbourne: J.L.Publications, 1985

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The aim of this investigation is to establish a data base of divers who dive or have dived with any medical contraindications to diving. At present it is known that some asthmatics dive and that some insulin dependant diabetics dive. What is not known is how many. How many with these conditions die is known. But how many dive safely with these conditions is not. Nor is incidence of diving accidents in these groups known.

If you are in such a group please make contact. All information will be treated as CONFIDENTIAL. No identifying details will appear in any report derived from the data base.

Write to
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The Editor's Offering

In this issue we have the full transcript of the inquest report on the death of two divers, on different days and diving from different boats, during an introductory dive on the Great Barrier Reef. The report discloses an unsatisfactory state of affairs in spite of what some divers regarded as the draconian Code of Practice operating in Queensland in 1994, when the deaths took place. It is a story which prompted the Coroner to suggest that the boat operators were putting money before safety. It is a story which has been replayed many times since diving became a popular pastime in the late 1960s. Inadequately trained, in these cases untrained, divers figure largely in the accident statistics. When someone takes an untrained person below the surface there is always the possibility of something going wrong, buoyancy problems and panic being most dangerous. When that someone has two people in his or her charge when Murphy strikes the choice is look after the one in trouble, which is the usual and commendable response, and leave the other underwater to look after himself or take them both to the surface, a response which is even safer. The latter response never features in the death reports. As most introductory dives are not one to one experiences this routine is likely to be followed by occasional deaths. Is the money made this way worth killing for? is a question that the Coroner answered in the negative.

Around the world working divers dive without training and many suffer decompression illness and death. The Cook Islands and Honduras are well apart but they share a lethal habit, untrained people, knowing nothing of how to avoid diving accidents, diving for money. Anyone who is able to help the Cook Islanders should contact Dr Lyndsae Wheen and offer their services for a humanitarian visit to those beautiful islands.

Most people think that dysbaric osteonecrosis is easy to diagnose. The X-rays will show it up. Radio-active scans often show hot spots which may or may not develop into X-ray changes. But what about a painful hip with no positive signs in any imaging modality? What should one do? The patient in our first original paper talked the surgeon into doing a total hip replacement in order to lose her pain. To everyone's surprise the femoral head showed the macroscopic signs and microscopy confirmed the unexpected diagnosis. The only known cause of osteonecrosis she had been exposed to was diving. One must rember that there are times when imaging will fail to show pathology.

In-water recompression, using oxygen, for decompression sickness occurring well away from a hyperbaric facility has its proponents and its opponents. Very few, if any, diving doctors are willing to countenance in-water recompression using air. Horror tales abound, in one case that the Editor knows of, the diver ended up with a week in a chamber on a Bass Strait oil rig (and still paraplegic), which meant no diving for Oceaneering while the chamber was occupied. A very expensive treatment. But there are places where in-water recompression, using air, appears to have better results, with approximately 88% complete recovery, than the average Australasian hyperbaric unit . Perhaps the Hawaiian diving habits, diving very deep on air, are ideally suited to immediate, that is within 5 minutes or less, recompression to the depth of relief, and a bit more, for ten minutes with a slow ascent rate with many stops. No one suggests that using air is as good as using oxygen in decompression but with the move towards evidence-based medicine figures of 88% complete recovery are impressive and worth investigating to discover why they occur. The likely candidate is time to compression. Occupational divers, on oil rigs, who are treated in a chamber immediately they present also have a very high rate of recovery, far higher than civilians who provide the work load for hospital based hyperbaric units. Anyone interested in doing a cost benefit study? It would be difficult to organise as delayed treatment is the norm and few people dive next to a chamber. Would anyone take the risks of legal action by treating people in the water with oxygen on the Great Barrier Reef? Would the boat owner be happy having the boat out for another two or three hours? However the pearl divers of Broome now treat bent divers with in-water oxygen as soon as they present at sea. This seems to be effective as there is no longer a steady transfer of paraplegic divers to the chamber at Fremantle. Readers are referred to the SPUMS Journal Pearl Diving Supplement (March 1996). Food for thought if not for action.

Diving is usually safe and enjoyable if one has the courage to say no to conditions one is not happy with. Safe diving requires a competent diver who knows how to avoid trouble and how to cope with the unexpected problem. A diver who knows his or her limitations and dives within them will normally survive to give up diving and die in bed or on the road. Divers who exceed the recreational diving envelope are putting themselves at extra risk, which is acceptable if the diver wants to do so but stupid if the diver does not realise what is being done. Using enriched air nitrox (EANx) introduces a new complication, the danger of an oxygen induced convulsion from a raised partial pressure of oxygen. In the Editor's experience recreational divers are poor depth keepers, they drift down and down, yet in the UK in 1995 a diver could get a Nitrox certificate after a purely verbal course with no check to see if they could actually manage their depth reliably. The only safe place to use nitrox is where the bottom is nearer the surface than the depth likely to cause a convulsion.

ORIGINAL PAPERS

DYSBARIC OSTEONECROSIS
DIVERS BONE ROT: A CASE REPORT

Carl Edmonds, Richard Harvey and Ray Randle

Abstract

The following case report calls into question the investigatory capabilities available for demonstrating or refuting dysbaric osteonecrosis (the "bone rot" of divers). It also implies a possible hazard associated with decompression meter and multi-level repetitive diving.

Key Words

Case report, dysbaric osteonecrosis, investigations, recreational diving.

Case history

A 36-year old female recreational scuba diver, otherwise very healthy and without a history of any predisposing factors for bone necrosis,[1] developed a pain in her left groin in November 1991. Initially this caused some problems in diagnosis, and it was variously diagnosed as a femoral hernia or an "irritable hip".

TABLE 1

DIVES UNDERTAKEN ON SIX CONSECUTIVE DAYS

	Maximum depth in metres	Duration in minutes	Surface interval in hours and minutes
Day 1	18	35	3.05
	12	43	2.34
	10	37	overnight
Day 2	12	47	2.15
	17	43	4.25
	12	42	overnight
Day 3	17	44	3.05
	18	30	2.20
	12	43	overnight
Day 4	21	20	6.25
	21	7	3.05
	9	45	overnight
Day 5	19	37	2.56
	15	41	2.54
	24	25	overnight
Day 6	18	38	3.40
	22	24	4.07
	9	37	overnight

Diving history

The patient is a recreational scuba diver who achieved her open water BSAC Certificate in 1988. She had performed only typical recreational dives well within the requirements laid down by the Oceanic decompression meter that she has used on all her dives. Most of her dives were less than 18 m and she rarely dived more than once a day. Nevertheless, she had logged 136 dives and more than 70 hours underwater. She had never undertaken decompression diving, nor had decompression sickness. The only excessive diving exposure comprised 20 dives in all.

Her only "eventful" dive was in May 1991 when she dived on a single dive to a maximum of 31 m for a total 21 minutes. She ascended from 31 to 19 m faster than usual, due to the strong current. She then performed 5 minutes decompression at 10 m and 5 m respectively. At no stage of this multi-level dive did the decompression meter suggest a need for decompression. The only other deep dive was a multi-level one to 37 m maximum, a week later, without incident.

Two months later she performed 3 dives/day for 6 consecutive days, diving from a live-aboard boat on the Great Barrier Reef in July 1991. The sequence of 18 dives (Table 1) was permitted by the dive computer as no-decompression dives (but not when assessed by the US Navy decompression tables).

Clinical progress

The symptoms progressed over 18 months, so that she became unable to carry out her normal occupational duties, other lower limb activities or weight bearing. Towards the end of this period she was progressively immobilised and more incapacitated by pain. Eventually she had a left total hip replacement in May 1993.

She was subjected to a number of investigations and operative procedures, to exclude possible causes of the symptomatology. The relevant positive investigations and procedures were:

A plain hip X-ray showed no abnormality (5th November, 1991).

The femoral canal area was explored (18th November, 1991). No abnormality was detected to indicate bowel herniation.

A laparoscopy was performed (22nd November, 1991), also without any abnormality being detected.

A technetium bone scan revealed a “hot spot” on the lower half of the left femur (27th November, 1991). An X-ray verified a 3 x 1.5 x 1.5 cm focus of benign appearing calcification in the medullary cavity at the junction of the distal and middle thirds, corresponding with the focal area of increased activity of the technetium bone scan. It was suggestive of either a medullary bone infarct or a benign enchondroma. As this lesion was the only pathology detectable, it was thought that the symptoms may have been due to that, and it was removed surgically (2nd December, 1991). This had no effect on the symptomatology.

Diving physicians and others retrospectively diagnosed a typical dysbaric osteonecrosis B2 type lesion on the X-rays. Such lesions are typically asymptomatic.

Because of the continuing symptomatology, an MRI scan was performed. This revealed no abnormality in the hip region but there was a cystic swelling of the left ovary. An ultrasound confirmed the presence of a left ovarian tumour. Oophorectomy was performed (26th February. 1992). This had no influence on the symptoms. An epithelial inclusion cyst was verified pathologically.

A local anaesthetic injection with Depo-Medrol (methylprednisolone) into the left hip produced relief of symptoms for some hours.

A CT scan of the hip region (26th May, 1992) revealed no abnormality.

An arthroscopy (14th September, 1992) of the left hip revealed normal articular surfaces, as far as could be ascertained, and no obvious reason for the symptoms.

Repeat technetium bone scans, repeat hip x-rays and tomograms, CT scans and MRI showed no abnormalities of the left hip.

A repeat injection of Depo-Medrol, with Marcain (bupivacaine), to the left hip successfully removed the pain for a few hours. Nevertheless, the patient was seen and examined by five independent orthopaedic groups over 18 months. There was conformity of clinical opinion, in that all agreed that the problem was with the left hip.

Investigations

In summary, the patient has had the following investigations, with the results in parentheses:

1 X-ray of the left hip:
November 1991 (calcified lesion with lower part of femur, possible B2 lesion)
February 1992 (NAD)
September 1992 (NAD)
January 1993 (NAD)

2 Tomograms left hip
January 1993 (NAD)

3 CT scan left hip and surrounding area:
May 1992 (NAD)

4 Technetium bone scan:
November 1991(hot spot in lower aspect of left femur, possible B2 lesion).
February 1992 (NAD)
May 1992 (NAD)
September 1992 (NAD)

5 MRI Scan
February 1992 (incidental left ovarian tumour observed)
May 1992 (NAD)
September 1992 (NAD)

6 Ultrasound
February 1992 (left ovarian tumour)

7 Arthroscopy
September 1992 (NAD)

Because of the difficulty in diagnosis, independent assessments were obtained of all the X-rays, technetium bone scans, CT scans and MRIs. No positive investigatory findings to support a diagnosis of hip disease were observed by any imaging specialist.

Pathological abnormalities

The only pathological abnormalities demonstrated in the above investigations were:

1 the bone lesion in the distal half of the left femur, similar to dysbaric osteonecrosis. The investigations supporting this included the X-ray and technetium scan.

2 left ovarian tumour demonstrated by MRI and ultrasound.

Both these lesions were removed early in the 18 month period but had no influence on symptomatology. Initially the bone pathology was thought to be consistent with an ossifying enchondroma.

It was decided, at the patient’s instigation and insistence, to carry out a total hip replacement, because of the severe incapacity. At surgery, when the hip was removed, there was a chondral softening and separation with adjacent areas of obvious collapse of the hyaline cartilage (Fig 1).

Gross pathology of the hip revealed a necrotic top of the femur. The cartilage appeared normal, apart from minor transverse splits and mild superficial changes. Histologically, the bone of the femoral head showed areas of normal bone and bone marrow, but with focal areas of bone and bone

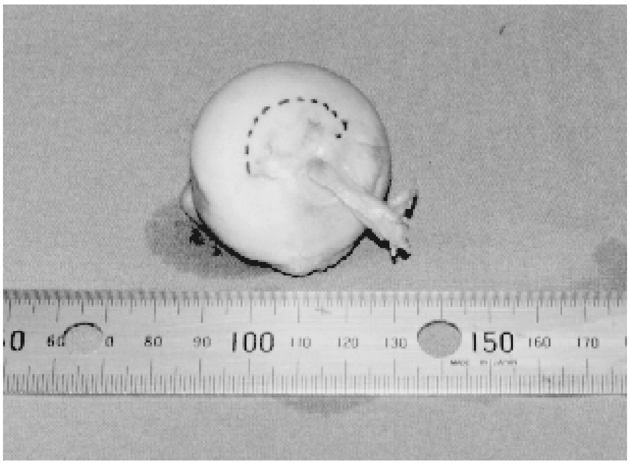

Figure 1. The area affected is under the dotted line.

marrow necrosis, and surrounding areas of bone repair. One of the necrotic areas was in the subchondral position, so that there was collapse of the overlying cartilage, which was fragmented. Occasional medium sized vessels contained thrombus, and this could have been part of the explanation for the multiple focal necrosis. There was no total or massive necrosis of the femoral head.

In summary, the appearances were those of small separate infarcts in the femoral head, immediately under the articular surface.

Discussion

At a radiological/pathology "Bone" meeting at Royal Prince Alfred Hospital in Sydney, the unusual characteristics of this case were reviewed and the unanimous opinion was that the radiological and imaging examinations did not demonstrate abnormal bone morphology of the left hip. In particular in the MRI examinations there is no evidence to suggest avascular necrosis within the femoral neck or head, nor joint effusion.

The only orthopaedic abnormality in any of the investigations was the lesion within the medullary cavity of the distal left femur on the plain x-rays, with scan findings consistent with dysbaric osteonecrosis.

The radiology assessments were performed by 5 different radiology groups and there was consistency with all the reports. The reports were available from the radiology and nuclear medical departments of 3 independent teaching hospitals.

The pathology of the hip does not indicate aetiology, however there was no doubt of the multiple and small aseptic necrotic areas under the articular surface. Pathology reports were obtained from Royal Prince Alfred Hospital, Sydney and the Royal Free Hospital, London.

This case illustrates four important problems:

1 The dependence that we have placed on the investigatory techniques (plain X-rays, tomograms, technetium bone scans, CT scans and MRI) to demonstrate significant lesions of dysbaric osteonecrosis, may not always be adequate to exclude such a lesion. This observation has been made elsewhere,[2] however no other reported case has had so many "negative" investigations performed.

2 The safety of the repetitive dives permitted by some of the decompression meters is in doubt. This has also been described elsewhere,[3] but in relation to decompression sickness more than dysbaric osteonecrosis. Many decompression meters allow recreation divers to undertake longer repetitive exposures to shallower (often multi-level) depths, more approximating to caisson workers' exposures than the square wave profiles of the conventional decompression dive tables. Whether this will make the recreational diver more prone to the occupational diseases of caisson workers (such as dysbaric osteonecrosis) is now in question.

3 There seems to be a paucity of pathological data to demonstrate the range of dysbaric osteonecrosis in humans, except for the more typical cases in which there is gross and extensive necrosis present. The pathology of non-traumatic idiopathic osteonecrosis has been described, and the fact that clinical symptoms can predate the articular surface involvement and the investigatory findings in this disorder is well recognised,[4] as is the multiple small vessel pathology which probably causes it.[5] This contrasts with the gross osteonecrosis presented in the common diving medical texts.[1,6]

4 This case demonstrates the possible superiority of clinical assessment over current imaging techniques, even though they are of great value when they are positive and to demonstrate clinically silent areas.[1,2, 4-6]

Acknowledgments

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EFFECTS OF HYPERBARIC PRESSURE ON THE GROWTH PLATES OF RATS

Peter Walker, Edward Bates, Wui Chung, William Walsh and Andrew Leicester

Abstract

Children with open growth plates are exposed to raised atmospheric pressures when scuba diving and during treatment for medical conditions such as osteomyelitis and gas gangrene in a hyperbaric chamber. This study was to determine if raised pressures have any detrimental effect on growth plate potential.

Immature rats were exposed for different periods of time to raised atmospheric pressures in a hyperbaric chamber. The animals were then sacrificed and their tibias examined macroscopically, radiologically and histologically. No differences in growth were detected between those exposed and the control groups. It is our conclusion that there are no detrimental effects to the growth plate of rats as a result of the pressures used in this study.

Key Words

Dysbaric osteonecrosis, hyperbaric research.

Introduction

Longitudinal bone growth is confined predominantly to the growth plates located at each end of the long bones. Cartilage is added at the top of the plate and is replaced by bone at the bottom. The cartilaginous portion of the growth plate is divided, by its morphology and function, into reserve, proliferative and hypertrophic zones.

The relationship between oxygen tension and bone and cartilage formation is a complex one. It is possible that oxygen tension may be an important physiological control mechanism governing growth at the epiphysial plate.

Brighton[1] studied the effects on growth of the epiphysial plate in vitro under different oxygen tensions using the costochondral junctions of rats. He showed that the highest growth rate occurred in 21% oxygen and the lowest growth rate in 90% oxygen. This and other experiments indicate that there is an optimal oxygen concentration for growth to occur and that high oxygen concentrations are detrimental to growth.[2,3] The explanations for this oxygen toxicity are numerous, but are not fully understood.

Oxygen is carried in the blood in two ways, bound to haemoglobin and in solution. By increasing oxygen partial pressures, either by scuba diving or in a hyperbaric chamber, the amount of dissolved oxygen increases in a linear fashion.[4]

Effective treatment of disorders using increased pressure was introduced in the 19th century. It is used in the treatment of gas gangrene, decompression sickness, gas embolism, carbon monoxide poisoning, cyanide poisoning, acute peripheral arterial insufficiency, crush injury, refractory osteomyelitis and to improve the viability of skin grafts. The treatment of some disorders may be prolonged, involving several weeks of daily hyperbaric exposures.

Destructive bone lesions have long been recognised as a latent problem associated with exposure to compressed gas atmospheres in divers. Extensive surveys have shown the incidence of dysbaric osteonecrosis to range from 4% in Royal Navy Divers (almost all of whom had been involved in experimental diving)[5] to 50% in Japanese shellfish divers.[6] The variation in incidence can be attributed to differences in frequency of exposure, degree of exposure to pressure and rate of decompression.

The high Japanese incidence has led to concern about repetitive diving in children and its effects on the growth plate. There is a widespread belief amongst diving instructors and medical personnel that diving may indeed be dangerous to the growth plates of children. There is no evidence in the literature to support or refute such a claim.

It is generally accepted that the formation of bubbles in tissue can occur during symptomless decompression carried out following conventional diving tables. Harvey stated that "the low tolerance of bone for inert gas supersaturation, may precipitate development of lesions when present day decompression tables are followed".[7]

The exact aetiology of osteonecrosis is unknown. Theories include the release of extravascular gas bubbles from fatty elements of bone, which exert sufficient pressure to compress blood vessels;[8] fat embolism produced experimentally;[9] release of vasoactive substances reducing blood flow to bones;[10] gas induced osmotic shift of fluids;[7] autoimmunity and dysproteinuria.[11] It is obvious from these proposed theories that the mechanism is not clear. What is known is that simple exposure to higher than normal pressures, without episodes of decompression illness, can cause areas of bone death. There seems no reason to believe why immature bone and more specifically growth plates cannot be similarly affected.

Numerous studies of mature bone have been performed in an attempt to simulate caisson disease. Colonna and Jones[12] were probably the first to examine the bones of animals exposed to repeated hyperbaric pressures. Smith and Stegall[13] produced radiological changes in miniature swine consistent with osteonecrosis. Successful attempts have been made to produce bone lesions in mice.[14]

An extensive search of the literature failed to find any long term studies on the effect of exposure to raised pressure on immature bone, especially the growth plate.

Using the rat as an experimental animal permits suitable numbers for statistical validation as well as allowing large numbers of animals to be exposed to identical environmental conditions. By using an animal model under standard physiological conditions we hoped to exclude any artificial results produced by in vitro models. We hoped to answer the following questions.

1 Are there any effects of hyperbaric pressure on the growth plates of rats?
2 Does increased frequency of exposures have an additive effect?
3 Is there a latent period between exposure and effect?
4 Can a single exposure have any effect?

From our results we hope to draw some conclusions regarding the possible effects of hyperbaric pressure on the growth plates of children during medical treatment as well as during underwater diving.

Methods

An pilot study using six rats was performed, under the supervision of the Ethics Committee and supervising veterinary surgeon, to determine if the protocol was safe. These rats were observed during the entire exposure through a glass window in the chamber. Throughout the pilot study and subsequent experiment there was no obvious change in behaviour to suggest any discomfort or symptoms of decompression sickness. The temperature in the chamber was recorded half-hourly.

After the rats were removed from the chamber they were observed for several hours and then several times a day for the next week. Again there were no signs of discomfort. It was decided that the protocol was entirely safe. During the subsequent exposures the rats continued to be monitored visually during and after the dives and on a daily basis thereafter. Beyond clinical observation no other tests of dysbaric stress were performed.

Thirty six male Sprague Dawley rats (4 weeks old) were placed at random into cages of six rats each. The rats were housed and kept under standard conditions under the guidance of the Animal Care and Ethics Committee (ACEC), in accordance with the NSW Government Animal Research Act (1985). Each rat was weighed initially and then at weekly intervals. Weight is a sensitive indicator of stress in rats.

The rats were exposed to a standard hyperbaric pressure protocol (Fig 1). The exposure was to the equivalent of 33 m of sea water for 100 minutes (including descent time of 15 minutes). Decompression stops were at 9 m for 10 minutes, 6 m for 40 minutes and 3 m for 75 minutes. This is a dive from the US Navy diving tables. Each group (6 rats per group) was exposed to increased pressure for 1 day, 5 days, 20 days or 40 days (Fig 2). At the beginning of the experiment all rats were 4 weeks old. Rats in groups 2, 3 and 4 were exposed five days a week at the same time each day. Twelve rats were not exposed to increased pressure and were used as controls.

At the end of the diving period half the rats from each cage were sacrificed using carbon dioxide inhalation. These rats (immediate sacrifice group) were all therefore twelve weeks old. The remaining rats (delayed sacrifice group) were sacrificed four weeks later (Fig 2).

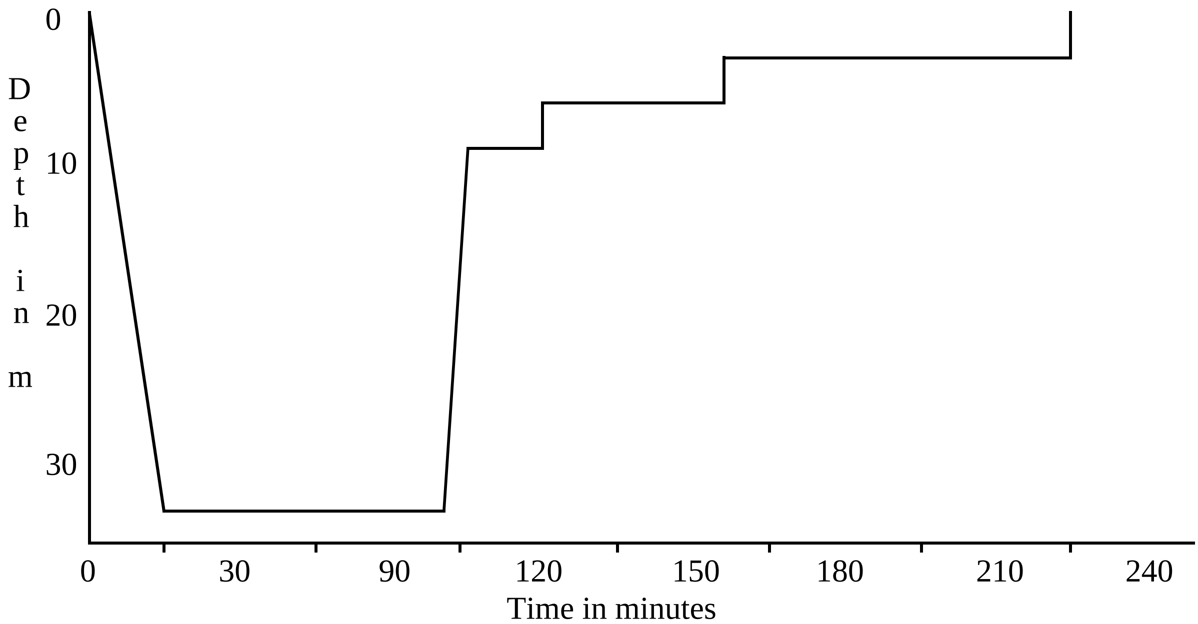

Figure 1. Hyperbaric pressure exposure protocol

Following sacrifice the femurs and tibias were dissected free of soft tissue and X-rayed using high resolution mammography film (Fig 3). Tibial lengths were measured from the tibial plateau to the tibial platform using a digital calliper.

The tibias were fixed in cold phosphate buffered formalin for 48 hours. Samples were demineralised in 0.5 M EDTA. Demineralised samples were sharply dissected and infiltrated with paraffin for sectioning. Five micron thick serial sections were taken through the middle of the upper tibial growth plate in the sagittal plane and stained with haematoxylin and eosin, Masson's trichome and alcian blue (Fig 4). Samples were examined under light microscopy using an Olympus BH-2 microscope. Morphological appearance was examined at 50x and 200x

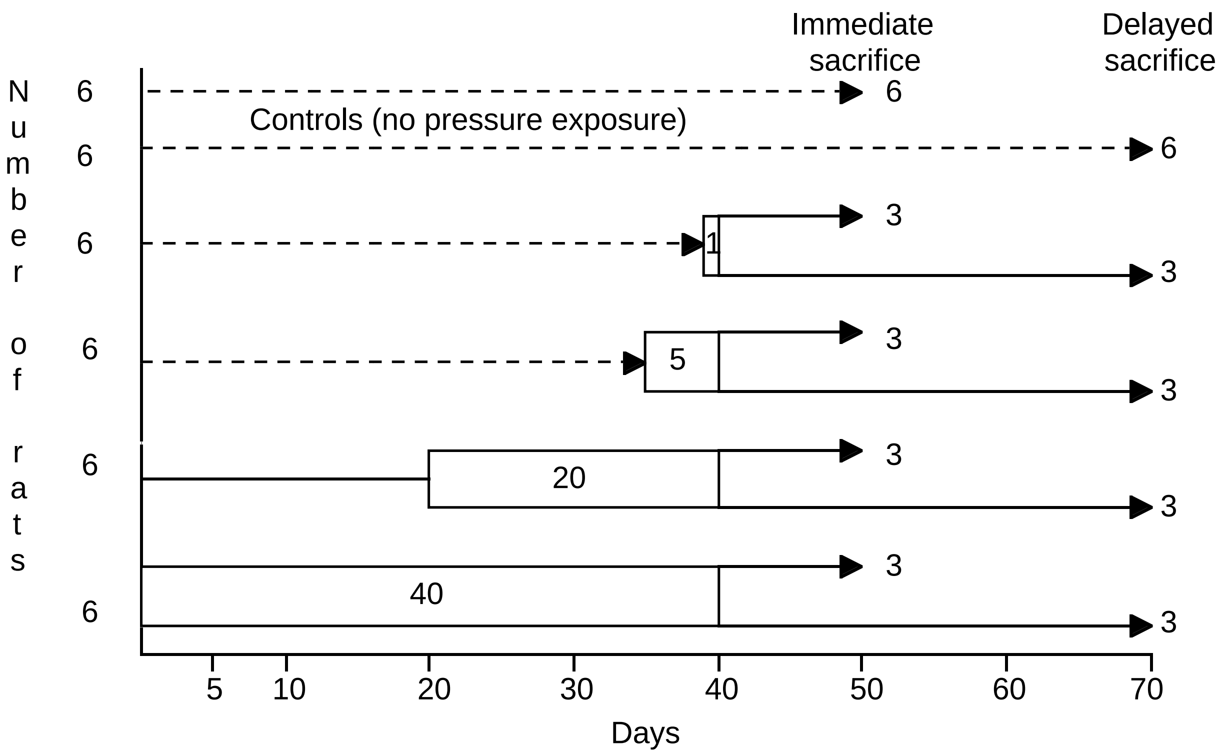

Figure 2. Periods of exposure and sacrifice times

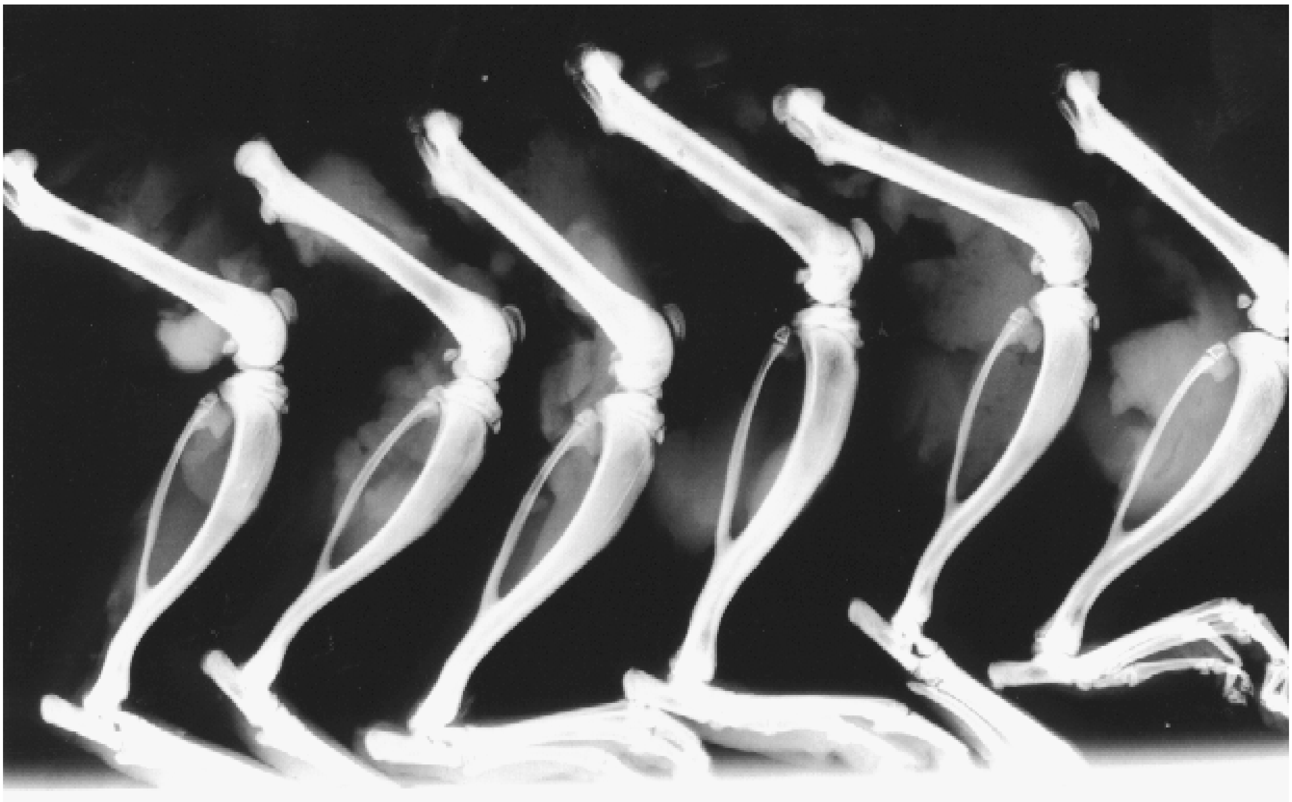

Figure 3. Radiographs of lower limbs of rats

magnification. Growth plate measurements were made using a high resolution Hitachi video camera connected to an Olympus BH-2 microscope and a MACIIVX equipped with a Scion Framegrabber. Morphometric measurements of the growth plate were made using NIH Image Software. The thickness of the growth plate for each section was measured in five different regions and averaged for each sample.

Data was statistically analysed using Statistical Analysis Software (SAS, Cary, NC, USA). A general linear model of an analysis of variance (ANOVA) was used to detect any difference between the groups.

Results

There were no signs of decompression illness. No rats developed a limp or any paralysis. The most sensitive indicator of stress in rats is their appetite and hence their weight. The rats in the pilot study and in the main experiment showed no differences in weight gain when compared with controls.

Tibial lengths and average thicknesses of the growth plate did not reveal any significant differences amongst the samples. The F ratio for group 1 and group 2 did not reveal any differences confirmed by post-hoc multiple comparisons.

Although no statistical differences were detected sample sizes were small. More sensitive methods such as electron microscopy or sophisticated histochemical techniques might have been able to detect subtle differences.

The slides were studied in detail by a pathologist with a special interest in growth plate pathology. The chondrocytes and surrounding matrix of the growth plate were normal. There was no evidence of haematopoietic cell necrosis, fat cell necrosis or osteonecrosis in the adjoining metaphyseal bone. No differences were found between any of the groups and the controls.

The X-rays were examined by a senior radiologist experienced in reading radiographs of rat bones. Several areas of questionable lysis, coarsening of trabeculations and some areas of sclerosis were seen, these were also present in the control groups, and assumed to be normal variants. There were no conclusive radiological findings.

Figure 4. Histological section of growth plate

Discussion

The proximal tibia of the Sprague Dawley rat is often used for quantitative histological study. Histomorphometric data from rats have usually proven an excellent predictor of human skeletal behaviour.[14] It has been shown by exposure of mature mice to hyperbaric pressures, that the proximal tibia is by far the most common region affected by osteonecrosis, the reasons for this being unknown.[8]

Despite adherence to strict diving protocols, osteonecrosis still occurs. In the Western world children are permitted to dive recreationally from before the age of 14 years, an age when rapid growth commonly occurs. This has led to concern regarding possible growth disorders amongst the recreational diving community. There has also been no questioning of the possible side effects of hyperbaric pressures for medical treatment. Only through well controlled studies will these questions be answered.

The rats used in this study were all exposed to well controlled realistic hyperbaric pressures outside the usual limits of recreational diving, which is limited to no-decompression diving. It was not our aim to produce decompression illness by exceeding known safe limits. All of the rats were the same age and sex making direct comparisons possible. It is our conclusion that exposure of immature rats to our hyperbaric pressure protocol failed to affect their interstitial or appositional growth. This finding answered our first quetion. As the answer was “No” the other three questions could not be answered for lack of dysbaric changes.

The physiological control mechanisms of growth at the epiphysial plate, especially the role of oxygen, are not yet fully understood. More studies are required to further our knowledge on this subject.

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Acknowledgments

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Dr P M Walker, MBBS, is a Paediatric Orthopaedic Registrar, Associate Professor E H Bates, FRACS, is Head, Department of Paediatric Orthopaedics, Drs W Chung, FRACS and A Leicester, FRACS, are Visiting Medical Officers in the Department of Paediatric Orthopaedics and Dr B Walsh, PhD, is Head of Biomedical Research, at the Sydney Children's Hospital, High Street, Randwick, New South Wales 2031, Australia.

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THE WORLD AS IT IS

WAS IT DCS?

Russ Gately

Key Words

Biology, envenomation, decompression illness, marine animals, treatment

Our company was contracted to bury a submarine power cable running from Surabaya to Madura Island in Indonesia. The work started in late August 1996 and continued until early November. The diving crew was all commercial divers, with the least experienced member having 5 years in the business. Two members of the crew were diving medical technician (DMT) trained.

The work entailed setting up a jet sled on the cable, which was then pulled along the length of the cable and cut a trench, into which the cable settled. Visibility was zero throughout the job. There were strong currents which necessitated planning all diving operations to coincide with slack water periods.

On completion of a dive to check the progress of the operation, one diver complained of unusual sensations, described by him as "like electrical shocks".

The onset of these symptoms was within 20 minutes of surfacing and, over the next hour, the symptoms extended to involuntary muscle contractions, pins and needles in the hands and feet, general overall pain and nausea. These symptoms were treated as DCS related. The diver was put on oxygen and transported to the hyperbaric facility at the Surabaya Naval Hospital.

As the diving supervisor, I was somewhat at a loss to explain why this diver should have DCS symptoms as the dive to 26 m for 18 minutes was well inside the no-decompression limit. The dive was routine with normal ascent and descent rates. The only incident was a minor jellyfish sting to the face while he was undressing. The diver complained that the sting was painful and a small welt was evident on his top lip. This was treated with vinegar and the pain and welt disappeared within 15 minutes.

On arrival at the hyperbaric facility the diver was seen by an Indonesian Navy doctor who had studied diving medicine at Aberdeen in the UK. After a brief consultation he was put into the chamber and a Table 5 was initiated. On arrival at 18 m he reported that he felt better but the "electrical shock" feeling was still present. On ascent to 9 m all the symptoms returned, however the table was continued without extension. The diver was admitted to the hospital on completion and given daily Table 5 treatments.

While all this was going on the diving work continued. Two days after the incident, I carried out a dive to check the sled. The position of the sled was marked by a buoy-line which was used as the downline with the dive boat secured to it. The dive was to 26 metres with a bottom time of 12 minutes. While I was ascending the down line I was stung by jellyfish tentacles which were entangled around the line by the current. The initial sting was to the back of my hand but in the process of trying to shake off the tentacles, the coverall cuff came undone which exposed my inner forearm which was also stung. The pain was intense and can best be described as like red hot wire being pressed against the skin.

On arrival at the surface there were red welts where I had been stung. Vinegar was used and the pain and welts rapidly disappeared with no visible evidence after about 30 minutes. One of the dive crew jokingly remarked that, if I started getting electrical shocks, I could go and join my colleague in hospital. Within 30 minutes I was experiencing intermittent shocks from my fingers and toes which progressed to violent muscle spasms, chest pain, visual disturbances and generally feeling like I had insulted Mike Tyson. This time I definitely knew it was not DCS related.

I was transported to the Naval Hospital where I was admitted and spent the next 4 days. The treatment consisted of large amounts of intravenous fluids, infused anti-histamines and cortisone injections with pethidine for the pain.

In hindsight it was interesting to note the similarity of symptoms with the sting of this particular jellyfish and CNS DCS symptoms. Our divers now know that hyperbaric treatment of jellyfish stings is not appropriate. Our fist aid kit now contains injectable antihistamine and corticosteroid, which we hope will never be needed. I have not been able to determine what type of jellyfish was responsible. Perhaps a SPUMS member may be able to decide from the symptoms listed.

In Des Gorman's lectures to my DMT course we were told to look beyond the obvious for other causes of similar symptoms. Very sage advice.

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The following report of inquest findings was provided by Mr E R Wessling, the Cairns Coroner, with permission for publication from the Human Rights and Administrative Law Division of the Queensland Department of Justice and Attorney General, GPO Box 149, Brisbane, Queensland 4001.

INQUEST INTO THE CAUSE AND CIRCUMSTANCES SURROUNDING THE DEATHS OF NICOLE HEIDEMARIE AHRENS AND FIONA WONG FINDINGS

Key Words

Barotrauma, cerebral arterial gas embolism, death, legal and insurance, pulmonary barotrauma, recreational diving.

For the purpose of assisting the relatives and lay persons at this inquest I indicate that where an inquest into a death is held, it is held for the purpose of establishing, so far as practicable, the fact that a person has died, the identity of the deceased person, when, where and how the death occurred and the person, if any, to be charged with murder, manslaughter, the offence of dangerous driving causing death or any offence set out in Section 311 of the Criminal Code as might be appropriate to the particular circumstances.

The Coroners Act requires that a Coroner give his or her findings in open Court and that the findings shall set forth so far as has been proved who the deceased was, when, where and how the deceased came to his or her death, the persons, if any, committed for trial. Subsection 5 of Section 43 provides that a Coroner shall not express any opinion any matter outside the scope of the inquest except in a rider designed in an appropriate case to prevent the recurrence of similar events.

No findings of a Coroner may be framed in such a way as to appear to determine any question of civil liability or as to suggest that any particular person is found guilty of any indictable offence or simple offence. So it is important that it be understood that any comments I make here on the evidence and the findings are made with those matters in mind.

The inquest is in relation to two diving incidents that occurred upon the Great Barrier Reef. The first occurring on 24 August 1994 at Upolu Cay involving the vessel *Sanduria* operated by Kevin Martin and Elizabeth Martin under the name of Sanduria Sail and Dive. The later occurring on 2 December 1994 at Michaelmas Cay involving the vessel *Compass* operated by John Heuvel under the name of Hostel Reef Trips.

This inquiry follows a more recent inquest conducted by myself into snorkelling activities undertaken by charter boat operators upon the Great Barrier Reef. The findings of that inquiry resulted in the implementation of a Code of Practice for Recreational Snorkelling.

The deaths of Nicole Ahrens and Fiona Wong have raised concerns about the present Code of Practice pertaining to recreational scuba diving which has become the subject of this inquiry. It should be remembered that although my comments relate to practices that existed in 1994 at the time of these deaths, they remain nonetheless relevant to present day practices. My belief in that regard has been reinforced from inquiries currently being undertaken into further deaths that occurred this year.

Before proceeding further with my findings, I emphasise for the benefit of the next of kin and remind those concerned that no longer will there be such an intolerable delay in completing inquiries into reef deaths. I am pleased to say that my previous recommendations to ensure an early disposal of these coronial matters have been implemented by those agencies concerned.

The evidence given at the inquest has highlighted the apathy that exists on the part of those persons involved in providing scuba diving activities on charter in open waters upon the Great Barrier Reef. The daily routine of tasks performed by operators and staff has led to complacency. Safety standards have been lowered and whether it be an instruction or otherwise the risks involved are being played down to passengers. The paying passenger is given no perception of the dangers involved and far too little is done to point out the risks of death or likely injury to health.

This is not surprising, of course, given the emphasise that is placed on the fact that it is a commercial venture.

One has to look no further than the evidence of Nicole Marie Walter to see how far some operators will go. Nicole, a young student at the time, was on a school excursion on board the vessel *Compass* that day.

She was encouraged to go scuba diving despite completing a medical questionnaire that she suffered from fainting spells. No inquiry was made by staff to assess her condition. Even more disturbing was the evidence that she was encouraged to pawn her ring to pay for the dive only to redeem it a week later from the charter operator, Hostel Reef Trips.

I shall diverge for a moment to address a further aspect relating to this school excursion trip.

Prior to going on this excursion each of the parents were asked to complete a questionnaire and consent form. The evidence of the Woree High School Principal, Mr Reich, is that all of the parents' forms were vetted prior to the boat trip and it was known that only one student had permission to go scuba diving. Yet, despite some 8 to 10 teachers assisting him with supervision of the students I am told that they were unable to prevent other students from going scuba diving.

It is cause for concern when the operator fails to take adequate precautions but it becomes of greater concern that those involved in the Education of our young people would place their lives at risk by not undertaking proper supervision and failing to adhere to the wishes of the parents.

I will provide the Hon. the Minister for Education with a copy of my findings and a transcript of the evidence of Mr Reich and Nicole Marie Walter for such action as he may deem necessary to ensure the future safety and welfare of students on such excursions. Medical clearances should be provided by students before the Education Department undertakes responsibility for school diving excursions.

Evidence adduced concerning the operations of the other vessel "Sanduria" by Sanduria Sail and Dive, has done little to improve the image of the industry. The operator had no maintenance schedules in place or records for the respective pieces of breathing apparatus at the time of the incident.

Documented procedures outlining responsibilities for scuba diving instructors and dive masters and diving procedures as recommended in the Code of Practice could not be provided at the time. The operator was unaware of the medical status of both Mr Coombe and Mr Melton who had been employed as dive instructor and dive master respectively. In fact, Mr Coombe was not in possession of a certificate indicating that he was medically fit to dive as recommended in the Code of Practice.

Whilst there have been other contributing factors to the deaths, the underlying cause has been "inexperience" on the part of the student participants. Until such time as those involved in this industry come to accept this fact and take appropriate precautions then it will be inevitable that further deaths will occur.

The inquest has heard that training agencies such as PADI go to extraordinary lengths to ensure that students are initially introduced to scuba diving in a controlled environment such as a swimming pool and yet, our community allows totally inexperienced people to dive in open waters far from emergency support services and sometimes in less than ideal weather conditions

Of course, there will always be those persons who accept the risks in exercise of their right to free choice. However, I see no reason why the industry should participate by failing to provide adequate supervision and counselling that results in emergency and other services being utilised at a high cost to the community.

I would prefer to see a situation where no scuba diving takes place in open waters until the person has undergone an introductory course in a controlled environment on shore and has been pronounced medically fit to undertake diving.

If that is unpalatable or not to be achieved and continued support is to be given to the current situation, then I recommend that the following legislation be introduced and changes made to the Code of Practice for Recreational Diving in an endeavour to reduce similar occurrences in the future. I canvass the changes in numerical order as follows:

1 The deaths of Nicole Ahrens and Fiona Wong occurred as a result of a barotrauma. On the evidence there was a failure in both instances to exercise direct supervision. Nicole Ahrens was relatively inexperienced having allegedly dived only once before and Fiona Wong having no experience at all. It appears that something occurred either in the manner of use of their equipment or otherwise which has caused them to panic and rise quickly to the surface. A barotrauma as we have heard occurs upon the diver re-surfacing quickly without exhaling which in layman's terms causes the lungs to expand and burst resulting in death. Once again, it is "inexperience" which causes the person to panic and of course, basic human instinct takes over causing the diver to return to his or her natural environment at the surface as quickly as possible.

Accordingly, I RECOMMEND that in-water supervision ratios in open water be restricted to a maximum of 4 students to one dive instructor or one dive master in respect of recreational divers who have undertaken an introductory course prior to open water diving and 2 divers to one dive instructor or one dive master in respect of those divers who have undertaken no prior introductory course.

I FURTHER RECOMMEND that the ratio of 4 students to one dive instructor or one dive master be observed with respect to divers who have limited experience e.g. only 3 to 5 previous dives undertaken.

I make no distinction between dive instructor and dive master. Despite their qualifications, he or she can only come to the assistance of a limited number of divers at the one time. I make no distinction between rough and ideal conditions. It is farcical to suggest it makes a difference if a person panics under ideal or rough conditions. The current ratios of 8 and 10 to 1 for Recreational Divers in Training and 4 and 6 to 1 for NonCertificate (Resort) Courses are a proven failure to date and cannot be sustained. As the inquest has shown, a ratio of 4 to 1 did not achieve the required supervision with respect to these incidents. On two occasions, the dive instructor in the case of Ahrens left other divers to go to the surface to assist the deceased on one occasion, and her husband on the other occasion, with weight belt problems. In the case of Wong, the diving instructor left other divers to surface and assist the deceased with BCD problems.

An additional problem with supervision arises from the wonderful attractions of the Great Barrier Reef which lure divers to wander off and become complacent. Nothing but the utmost diligence is required from dive instructors and dive masters to ensure "direct" supervision is maintained at all times

The attitude of the instructor on board the vessel *Compass* towards supervision is alarming and should be a real concern to the operator and the industry as a whole. I refer to that conversation which the deceased and her friend, Monica Ng, had with the instructor immediately before the dive and I quote "We asked the instructor how deep we would go down this time and he told us about 10 metres but we didn't want to go down that deep. The instructor told us that we didn't have to follow him down that much if we don't want to". What was he going to do? Just leave them there!

2 In addition to the reduction of ratio of divers to supervision, I RECOMMEND that a system of voice communication or a technique called budding banding be adopted. Voice communication between the instructor below and the vessel on the surface would provide for an early warning system with respect to divers in trouble enabling the instructor to call for help and assistance. Time has been shown to be of the essence in such situations and any system which can reduce delay in rendering assistance must be considered. Buddy banding would also ensure that the group remains together and reduces the risk of persons wandering off. These techniques are canvassed in the evidence of Brian MacDonald Marfleet.

3 The inquest into these deaths resulted in an examination of the equipment used. Whilst the evidence does not disclose that the equipment used contributed directly to the death of these persons, it did show that the upkeep of the equipment was far from satisfactory. The Code of Practice for Recreational Diving, at paragraph 2.4 on page 14, sets forth guidelines to be implemented with respect to equipment. I am not satisfied from my inquiry that charter boat operators have been embracing these guidelines with any enthusiasm.

The guidelines are expressed in open terms e.g. what are "appropriate inspections"? It has been brought to my attention in the evidence of Mr Marfleet that manufacturer's instructions and Australian standards are not based on the type of usage that the diving equipment receives in the activities conducted by charter operators. Numerous people undertake scuba diving on a daily basis seven days per week on board these vessels operating out of the port of Cairns. It has been difficult to set any period for service of equipment based on the limited evidence available to me at the inquest but I would venture to suggest that regulators should be serviced at least every 14 days and other equipment at least once a month.

In any event, I RECOMMEND that legislation be introduced by way of amendment to the Workplace Health and Safety Act and Regulations to ensure that charter boat operators maintain a schedule of inspection and repair records for all diving equipment. That all diving equipment carry a serial identification number that can be related to the schedule. That all diving equipment including regulators be inspected within a period set by the Hon. the Minister for Employment and Industrial Relations as he may deem fit.

4 Finally, the issue of medical questionnaires has arisen during the inquest. On the evidence before me, I find it difficult to perceive how such questionnaire serves a useful purpose at the present time. It would seem on the evidence that charter operators principally use such forms to tack on a clause to merely absolve themselves from liability with little or no regard to the medical disorders declared by passengers. Both the forms used by the charter operators and that approved under the Code of Practice are defective in one very important aspect.

The questionnaire invites the person to disclose medical disorders particularly those listed thereon, but does not set out distinctly whether it is safe to go scuba diving if one happens to tick YES to any of those particular medical disorders.

As stated by Dr Deakon, persons suffering sinusitis as disclosed by the deceased, Fiona Wong, in her medical form and persons suffering from fainting spells as disclosed by Nicole Walter in her medical form should not dive. It could prove fatal to do so.

I also note that medical questionnaires suggest that you should seek your own medical advice. Where does one get qualified medical advice once the form is suddenly handed to you on board the vessel at sea?

I RECOMMEND an immediate review of the prescribed medical declaration to include words which clearly indicate and give advice to the passenger that if you have ticked YES to any of the medical disorders listed you MUST not scuba dive. My suggestion of the wording is “The medical disorders listed on this form are incompatible with safe diving and places yourself at real risk of death or permanent injury to health. If you have ticked YES to any of the questions you MUST not undertake scuba diving”.

I FURTHER RECOMMEND that legislation be introduced by way of amendment to the Workplace Health and Safety Act and Regulations that the prescribed medical declaration must be made available by charter boat operators and completed by passengers prior to diving.

I FURTHER RECOMMEND that the Code of Practice for Recreational Diving provide that employers encourage staff to strenuously advise passengers not to undertake scuba diving in circumstances where medical disorders are either disclosed, made known or are observed.

In addition, greater public awareness programs to the dangers of diving with a medical disorder should be undertaken by the tourism industry as a whole in co-operation with local authorities.

I now move to my formal findings required under the Coroners Act as I alluded to at the outset.

In relation to the diving incident on 24 August 1994, I find that the deceased was one Nicole Heidemarie AHRENS, a female person aged 40 years who formerly resided at Rothenhauschaussee 17A, 21029 Hamburg, Germany.

I find that the deceased, who was a passenger on board the charter vessel *Sanduria,* died on 24 August 1994 at the Cairns Base Hospital as a result of injuries sustained in a diving incident that occurred at Upolu Cay upon the Great Barrier Reef off Cairns on 24 August 1994.

I find the cause of death to be

1 (a) salt water drowning

(b) pulmonary barotrauma air embolism and mediastinal haemorrhage.

In relation to the diving incident on 2 December 1994, I find that the deceased was one Fiona Hang Ngor WONG, a female person aged 36 years of age, formerly of Canada.

I find that the deceased who was a passenger on board the charter vessel *Compass* died on 3 December 1994 at the Cairns Base Hospital as a result of injuries sustained in a diving incident that occurred near Michaelmas Cay upon the Great Barrier Reef off Cairns on 2 December 1994.

I find the cause of death to be

1 (a) cerebral artery gas embolism

(b) severe pulmonary barotrauma.

Upon consideration of all the evidence adduced in this inquest, I find that there is not sufficient evidence upon which I would commit any person for trial in relation to these deaths. No person is committed for trial.

Copies of the transcript of the relevant evidence together with a copy of these findings to be delivered to the appropriate Ministers of the Crown to which I have referred.

The Inquest is closed.

E R Wessling
Coroner
16 May 1996

The following has been provided by Mr Brian Marfleet, Workplace Health and Safety Inspector, to inform SPUMS members of the changes to medical certification requirements which came into force in Queensland on 2/7/97.

SAFETY LINK
Medical Examinations for Underwater Divers
Information for Doctors

Purpose

To advise doctors who carry out diving medical examinations on people involved in underwater diving of the -

- requirements under the ***Workplace Health and Safety (Underwater Diving Work) Compliance Standard 1996***

and

- the recommendations given in the **Advisory Standard *"Code of Practice for Recreational Diving and Snorkelling at a Workplace"***

What the Workplace Health and Safety (Underwater Diving Work) Compliance Standard 1996 requires

The *Workplace Health and Safety (Underwater Diving Work) Compliance Standard 1996* requires employers, self-employed people and workers doing any type of underwater diving work to hold a **current certificate of medical fitness** to dive. This applies to all types of diving work.

What is a current certificate of medical fitness to dive?

A current certificate is one that is less than 12 months old which has not expired, been revoked or superseded. People doing underwater diving work will need to have an annual medical examination to obtain a "current" certificate.

A certificate *of medical fitness to dive* is a certificate that -

a on its face is issued by a doctor who has satisfactorily completed training in diving medicine approved by the Board of Censors of the South Pacific Underwater Medicine Society (SPUMS); and

b contains the following information -
- the name of the person who holds the certificate
- the date the certificate was issued
- shows that the person is medically fit to dive according to the fitness criteria in AS 2299 1992 *Occupational Diving*, appendix A, paragraph A3
- any limitations on diving imposed by the doctor.

While AS 2299-1992 fitness criteria specify a minimum age of 18 for divers, the compliance standard allows persons under the age of 18 to hold a certificate of medical fitness to dive as there are circumstances where a person under the age of 18 may wish to do underwater diving work. Whether a person under 18 is declared fit to dive or not is a matter for the doctor's discretion. The type of diving work the person intends to do may be a relevant factor in assessing whether the person is fit to dive.

If the person is under the age of 18, the doctor may issue a certificate but the certificate must show -

- that apart from being under 18, the person is medically fit to dive in accordance with AS 2299-1992, appendix A, paragraph A3 and no limitations on diving are needed even though the person is under 18; or
- that apart from the limitations on diving stated on the certificate, the person is medically fit to dive in accordance with AS 2299 - 1992, appendix A, paragraph A3. The certificate must show which, if any, of the limitations are imposed because the person is under 18.

As employers, self-employed people and workers who do underwater diving work must hold a certificate that shows the above information, it would be useful if doctors issuing certificates made sure all the relevant information is shown on the certificate.

Training in diving medicine

The compliance standard requires the certificate to be issued by a doctor who has satisfactorily completed training in diving medicine approved by the Board of Censors of SPUMS.

Doctors may issue a certificate of medical fitness to dive if they have satisfactorily completed any of the following training -

- Royal Adelaide Hospital Basic Course in Diving Medicine and the Advanced Course in Diving and Hyperbaric Medicine
- Royal Australian Navy Submarine and Underwater Medicine Unit Basic Course, Advanced Course or the Medical Officer's Course
- Diving Medical Centre Medical Examiner Course
- Fremantle Hospital Medical Assessment of Divers Course
- Royal New Zealand Navy Basic Course
- Christchurch Hospital Basic Course
- Institute of Naval Medicine (UK) Medical Examiner Course
- United States Navy Diving Medical Officer Course

If the Board of Censors of SPUMS approves any new training in diving medicine, these courses also will be covered by the compliance standard. Because SPUMS recommends courses of 10 days duration or more as the most appropriate training for carrying out AS 2299-1992 medical examinations, it needs to be noted that the compliance standard permits a doctor who has satisfactorily completed any training in underwater medicine approved by the Board of Censors to issue certificates of medical fitness to dive, and that not all approved courses meet the recommended period of 10 days.

What the Advisory Standard "Code Of Practice for Recreational Diving and Snorkelling at a Workplace" states:

For non-certification course divers

The employer or self-employed person at a workplace should ensure that a person intending to do a non-certification course in underwater diving has satisfactorily completed a medical declaration containing information outlined in Appendix 3 of the Advisory Standard/Code of Practice.

If any medical condition is disclosed, medical advice should be sought from a diving medical practitioner before any diving takes place.

For people doing entry-level certification for open water diving

These people should be certified as being medically fit for diving in accordance with

- Appendix A - Prediving Medical Examination for Prospective Recreational Scuba Divers; and
- Appendix B - Typical Medical Form for Prospective Recreational Scuba Divers of AS 4005.1 - 1992.

This certification should be provided in English by a diving medical practitioner within 90 days prior to the commencement of training.

The employer or self-employed person at a workplace where people are engaged in entry-level recreational certification training should ensure that all students are certified as being medically fit for diving.

Advanced and/or speciality certificate training

These people should be certified as being medically fit for diving through -

- medical certification within the past 5 years with no injury or illness since;

or, if over 40 years of age

- the same medical certification as required for people doing entry level certification for open water diving.

The employer or self-employed person should ensure people engaged in advanced and/or speciality certificate training meet the above criteria for medical fitness to dive.

1. Example only of information a certificate of medical fitness to dive must show for a person who claims to be over 18 and has no limitations imposed on medical grounds.

Diving Medical Certificate

Issued by:	*who has satisfactorily completed training in diving medicine approved by the Board of Censors of the South Pacific Underwater Medicine Society.*
Issued to:	
Date of Issue:	
Fit to Dive:	under AS 2299-1992, appendix A, paragraph 3

2. Example only of information a certificate of medical fitness to dive must show for a person who claims to be over 18 and has a limitation imposed on medical grounds.

Diving Medical Certificate

Issued by: *who has satisfactorily completed training in diving medicine approved by the Board of Censors of the South Pacific Underwater Medicine Society.*

Issued to:

Date of Issue:

Fit to Dive: under AS 2299-1992. appendix A, paragraph 3
insert limitation

3. Example only of information a certificate of medical fitness to dive must show for a person who claims to be under 18 and has no limitations imposed on medical grounds.

Diving Medical Certificate

Issued by: *who has satisfactorily completed training in diving medicine approved by the Board of Censors of the South Pacific Underwater Medicine Society.*

Issued to:

Date of Issue:

Fit to Dive: under AS 2299-1992, appendix A, paragraph 3 (apart from being under 18)
No limitations on diving are needed even though the holder of this certificate is under 18.

4. Example only of information a certificate of medical fitness to dive must show for a person who claims to be under 18 and has a limitation imposed on medical grounds because* the *person is under 18.

Diving Medical Certificate

Issued by: *who has satisfactorily completed training in diving medicine approved by the Board of Censorsof the South Pacific Underwater Medicine Society.*

Issued to:

Date of Issue:

Fit to Dive: under AS 2299-1992, appendix A, paragraph 3 (apart from being under 18)
insert limitation
This limitation on diving is imposed because the holder of this certilicate is under 18

Further information can be obtained by contacting

BRISBANE	Brian Marfleet	(07) 3872 0677	or Workplace Health and Safety
	Michael Williams	(07) 3872 0678	
			Freecall: 1800 177 717
CAIRNS	Chris Coxon	(070) 523 910	
	Robert Newie	(070) 523 908	Internet: http://www.gil.com.au/va/whs_home/whs.htm

SPUMS NOTICES

SOUTH PACIFIC UNDERWATER MEDICINE SOCIETY DIPLOMA OF DIVING AND HYPERBARIC MEDICINE.

Requirements for candidates

In order for the Diploma of Diving and Hyperbaric Medicine to be awarded by the Society, the candidate must comply with the following conditions:

1 The candidate must be a financial member of the Society.

2 The candidate must supply documentary evidence of satisfactory completion of examined courses in both Basic and Advanced Hyperbaric and Diving Medicine at an institution approved by the Board of Censors of the Society.

3 The candidate must have completed at least six months full time, or equivalent part time, training in an approved Hyperbaric Medicine Unit.

4 All candidates will be required to advise the Board of Censors of their intended candidacy and to discuss the proposed subject matter of their thesis.

5 Having received prior approval of the subject matter by the Board of Censors, the candidate must submit a thesis, treatise or paper, in a form suitable for publication, for consideration by the Board of Censors.

Candidates are advised that preference will be given to papers reporting original basic or clinical research work. All clinical research material must be accompanied by documentary evidence of approval by an appropriate Ethics Committee.

Case reports may be acceptable provided they are thoroughly documented, the subject is extensively researched and is then discussed in depth. Reports of a single case will be deemed insufficient.

Review articles may be acceptable only if the review is of the world literature, it is thoroughly analysed and discussed and the subject matter has not received a similar review in recent times.

6 All successful thesis material becomes the property of the Society to be published as it deems fit.

7 The Board of Censors reserves the right to modify any of these requirements from time to time.

OBITUARY

RAYMOND ROGERS

On 28/5/97 Ray Rogers, one of few non-medical full members of SPUMS, died in his sleep at his home in Blairsville, Georgia, USA.

All those who attended the 1990 Annual Scientific Meeting in Palau will remember Ray Rogers. It was his first SPUMS meeting and it was plain that he was enjoying the meeting, the diving and getting to know the members. A gregarious and friendly dentist from Georgia, he chatted to everyone. When he returned home he, Dr Lori Barr and Steve Dent started the North American Chapter of SPUMS.

A diver for many years he had become disenchanted with the USN Repetitive Dive tables as keeping him out of the water for too long between dives when the dive went below 12 m (40 ft). He researched the origins of the USN tables and unearthed the fact that the controlling tissue for the Residual Nitrogen calculations was the 120 minute compartment. Knowing that the tables are mathematical predictions rather than “tablets of stone” handed down by the Almighty (a misapprehension prevalent in the US recreational diving community 20 years ago), and having a calculator, and later a computer with a mathematics program, he set about modifying the USN tables to allow divers to return to the water safely sooner than the USN did.

His years of diving had shown him that very few recreational divers could make a tank last long enough to accumulate much nitrogen in the 120 minute compartment when the tissue loading was calculated using the USN tables algorithm. Typical recreational dives, however, resulted in some nitrogen loading in the 60 minute tissue. His calculations showed that using the 60 minute tissue as the controlling compartment for residual nitrogen calculations would allow the same time underwater on the first dive and a shorter surface interval before the second dive while still maintaining the same levels of under-saturation in the 60 minute tissue as the USN tables. In 1976 Dr Merrill Spencer had suggested that the no-stop limits should be shortened to avoid Doppler-detectable bubbles. So Ray recalculated the tables. With the help of Diving Science and Technology (DSAT), a subsidiary of PADI, Ray produced the Recreational Dive Planner which was adopted by PADI as tables and The Wheel.

Those who were not in Palau in 1990 read about Ray’s ideas and tables in various SPUMS Journals.[1-5] In 1994 DSAT published *The DSAT Recreational Dive Planner. Development and validation of no-stop decompression procedures for recreational diving* by R W

(Bill) Hamilton, Raymond Rogers, Michael Powell, Richard Vann with Richard Dunford, Merrill Spencer and Drew Richardson. A review of the book was published in the Journal.[6]

SPUMS extends it sympathy to his family.

References

1 Rogers R. The development of the Recreational Dive Planner. *SPUMS J* 1991; 21 (2) Apr-June: 98-106

2 Powell MR and Rogers RE. Doppler ultrasound monitoring of gas phase formation and resolution in repetitive diving. *SPUMS J* 1991; 21 (2) Apr-June: 123 (Reprinted from *Undersea Biomed Res 1989; 16 (Suppl): 69*)

3 Rogers R. Testing the Recreational Dive Planner. *SPUMS J* 1991; 21 (3) July-Sept: 164-171

4 Rogers R. The recreational dive planner and the PADI experience. *SPUMS J* 1992: 22 (1) Jan-Mar; 42-46

5 Rogers R. Developing the DSAT diving computer model. *SPUMS J* 1994: 24 (4) December: 233-237

6 Hamilton RW, Rogers RE, Powell MR, Vann RD, Dunford R, Spencer MP and Richardson D. The DSAT Recreational Dive Planner. Development and validation of no-stop decompression procedures for recreational diving. *SPUMS J* 1994; 24 (4): 206.

John Knight

Key Words
Obituary.

MINUTES OF THE NEW ZEALAND CHAPTER OF SPUMS AGM 1997

Held on 17/4/1997 at the Waitangi Resort, Waitangi.

The meeting opened at 1800.

Present

Tony Slark, Courtenay Kenny, Paul Wakely, Alastair Leggat, Simon Mitchell, Angela Hancock, Michael Kluger, Rees Jones, Dave Pemberton, Graham McGeoch, Mike Davis, Sharon Mullender, Martin Rees, Morgens Poppe, Mike Davis, Lyndsae Wheen.

Apologies

Chris Strack, Chris Morgan, A Gibson, W Thompson, P Jennings, Simon Cotton, Andrew Hurley, N Hutchison, Julian Roberts, John Aiken, Andy Veale.

1 Minutes of the previous AGM

Accepted as a true record.

2 Business arising from the minutes

2.1 Mike Davis pointed out that the Treasurer's report as tabled was inaccurate. The account balance appears high, this is due to monies held for the 1997 ASM.

2.2 The issue of refund of fees for the cancelled dive trip during the 1995 meeting in Tairua still needs to be clarified.

2.3 Ongoing discussions about a membership drive for the NZ chapter. Simon Mitchell advised that attendees of the Diving Medicine course would be strongly encouraged to join SPUMS. Lyndsae Wheen suggested that medical students should be informed about SPUMS. Simon Mitchell was to raise this with Des Gorman. A column or a flyer in NZ Doctor, or similar magazine, promoting SPUMS was mooted by Courtenay Kenny. Mike Davis proposed a notice to all dive clubs about SPUMS and advertising full and associate membership.

3 Correspondence

None.

4 Chairman's Report 1996-1997

The Chairman's time has been largely occupied with convening the SPUMS 25th ASM at Paihia, Bay of Islands. This has left little time for other SPUMS pursuits. In particular I am aware that the membership campaign with which the committee was tasked has had no attention. Chapter support for the ASM, the first ever, and perhaps the last, on our home turf, has been particularly disappointing to me, especially given the high quality of the scientific program. I am sure the SPUMS Executive will have noted this. My thanks to those New Zealanders who have come to Paihia. A society is only successful if members support its activities. The general lack of interest (with a few notable exceptions) within the diving industry reflects the gulf between our two groups. During my term of office we have provided three excellent meetings for the Chapter. Each has been poorly attended, numbers being swollen by others interested in diving medicine but not SPUMS members. This being so, it is hard to know what New Zealanders want from this society!

Mike Davis 15/4/97

5 Secretary/Treasurer's Report 1996-1997

5.1 Secretary's report

A comprehensive mailing list is at last in working order. This substantially reduces the time and effort to send out any newsletters. The last newsletter was faxed to 80 members, which cost less than half the costs of stamps, and was posted to the rest. An e-mail database is also up and running.

As a result of advertisements placed in the NZ Medical Journal, many Medics have indicated interest and all have been mailed with information, application forms and Paihia Conference brochures. Hopefully most of these will become members. People are still writing and faxing requests for information.

Unfortunately I have been unable to persuade the RNZCGP to award CME points for attendance at Scientific meetings but have not given up yet.

I have not had time to set up a Web home page yet for SPUMS. Two initial attempts "fell over" but if there is sufficient interest, it could be fairly easily done, at a cost of about $200. It is hard to say how much interest it would generate, but it could be considerable.

5.2 Treasurer's report

All accounts now entered in 'Quicken', an electronic accounting package. Attached are the full accounts. The BNZ Scientific Meeting account has been transferred to an ASB account. The Founders Account remains untouched. The two other ASB and BNZ accounts have been closed and their funds transferred to the ASB SPUMS Scientific Meeting account.

Perusal of the 'All Accounts' Report shows that the total assets of SPUMS NZ is $22,034.36. This includes an amount in the ASB SPUMS Scientific Meeting account which obviously will vary considerably in the near future and Mike Davis can answer questions about. If this account is ignored the total assets are $5,150.00.

Christopher Morgan 15/4/97

6 Election of Officers

Nominated for Chairman : Dr Michael Kluger and for Secretary/Treasurer : Dr Lyndsae Wheen. Proposed: Mike Davis; seconded: Courtenay Kenny; carried.

7 Other Business

7.1 Mike Davis reported that the Founder's Fund, which was to have been used for the ASM if needed, remains untouched at approximately $3,500. Courtenay Kenny moved that the Founder's Fund be used to contribute to the cost of a visiting speaker for the SPUMS (NZ) meeting 1998. Carried.

7.2 General discussion took place about CME points for the annual meetings. It was pointed out that the Royal Australian College of GPs and the Australian and New Zealand College of Anaesthetists both accept the ASM for CME points. It was agreed that this question should be re-addressed with the RNZCGP.

8 Venue of 1998 meeting

Courtenay Kenny and Simon Mitchell agreed to honour the commitment made at the 1996 AGM to host the meeting at the RNZN base at Devonport. Tutukaka was proposed as a good diving base.

The meeting closed at 1900.

Key Words

Meeting.

NEW ZEALAND CHAPTER OF SPUMS ASSETS AND LIABILITIES AS OF 15/4/97

Bank accounts	Balance at 15/4/97
SPUMS Scien-12-3155-003265-00	16,884.36
Founders Account	3,324.13
SPUMS BNZ No 2 account	0.00
SPUMS NZ ABS-12-3101-0052348-00	1825.87
Total	22,034.36
Liabilities	0.00
Total Assets	**22,034.36**

MINUTES OF THE SPUMS COMMITTEE MEETING

held on 15/4/97 during the
1997 Annual Scientific Meeting (ASM) in New Zealand

Opened 2005 New Zealand Time

Present

Drs G Williams (President), C Meehan (Secretary), R Walker (Treasurer), J Knight (Editor), C Acott, V Haller and M Kluger (Committee members).

Apologies

Drs D Gorman (Past President), Dr D Davies (Education Officer), M Davis (New Zealand Representative).

1 Minutes of the previous meeting (19/10/96)

Read and accepted as a true record after minor adjustments. Proposed J Knight, seconded C Acott.

2 Matters arising from the minutes

2.1 North American Chapter. There needs to be further promotion of SPUMS in the USA. It was suggested that some SPUMS Journals be taken to the Undersea and Hyperbaric Medical Society (UHMS) meeting, as well as to other significant overseas meetings. Articles about the Society could be published in various dive magazines, e.g. Skin Diver, The Undersea Journal (PADI). It was suggested that the SPUMS introductory form be updated.

2.2 New Zealand 1997 ASM. All details of the ASM have been going according to plan.

2.3 Future ASM venues.

1998 Palau, 8th-17th May. An update was given by Dr Acott. He provided an information sheet with an outline of expected costs. It was suggested because of the currents that for safety every divers should carry a Safety Sausage, a mirror, a strobe and possibly a dye capsule.

1999 Layang Layang. Dr Kluger selected to convene the meeting.

2000 suggested venue Fiji, Castaway Island.

2.4 Indemnity policy. This is still being researched by Dr Williams.

2.5 Role of the Convener. This document had not been received.

2.6 Ex-Presidents Committee. Members of this committee must be financial members. An update on this committee will be sought from Dr Gorman. The committee will be meeting in a few days.

2.7 Diving Doctors List. This is being maintained by Steve Goble of the Royal Adelaide Hospital Hyperbaric Unit. An asterisk has been placed beside the name of all doctors who have completed a course of 10 or more days duration. A new DDL application for needs to be designed to facilitate this.

2.8 SPUMS Journal Index. Available for Macintosh. Will be available for other operating systems soon.

2.9 Oxygen equipment for dive boats. Update on costs of purchasing equipment for ASMs

2.10 Posting of SPUMS Journal. To be mailed in plastic wrap in future. Dr Knight to co-ordinate.

2.11 Inventory of SPUMS equipment etc. Not all members have completed this.

2.12 SPUMS European representative. Dr Henrik Straunstrup has agreed to carry out this role. Dr Williams will discuss this further with him.

2.13 SPUMS on the Internet. The Secretary of SPUMS has a home page web site at http;//www.ozemail.com au/~cmeehan/index.html. Dr Meehan will update this home page and it will be posted on the net. The page at present gives basic information about the Society and includes an application form to join SPUMS and to be entered in the Diving Doctors List. Details of the SPUMS Committee, including e-mail and facsimile numbers will be added. It is hoped that links will be set up to facilitate access to relevant sites. Information about the ASM should be able to be accessed from this site, as well as a sample of Journal articles, workshop statements, pending courses and other conferences.

2.14 Financial assistance for DES. Dr Acott provided an update.

2.1.5 Committee positions being for two years. Briefly discussed but no decision made. If the idea is adopted a motion to change the constitution will have to be put to the next AGM.

3 Treasurer's report

This was presented to the Committee. No audited report was available. There appears to be no need to increase the membership fees for 1998.

4 Correspondence

4.1 Letter from Dr Douglas Walker re Project Proteus. This was passed to Dr Williams to be discussed at the Past-Presidents Committee later in the week.

4.2 Letter re Diving Medical from Dr Kevin Ho-Shon. As SPUMS is not a regulatory body no action could be taken.

5 Other business

5.1 Request from Dr Knight that his honorarium be CPI indexed. As previously decided the honorarium is to be reassessed every year at the Committee Meeting held during the ASM. Any changes to take place at the beginning of the new financial year. It was agreed that the honorarium be increased, by $600 (the CPI increase rounded off) a year, to $1300 a month ($15,600 a year) from July 1st 1997.

5.2 Election of Officers. The results of the ballot was presented to the Committee. The details will be presented at the Annual General Meeting.

Closed at 22.45.

SPUMS ANNUAL SCIENTIFIC MEETING 1998

Palau Pacific Resort 8th to 17th May

Those who wish to present papers are asked to contact
Dr Chris Acott, Hyperbaric Unit, Royal Adelaide Hospital
North Terrace, Adelaide, South Australia 5000.
Phone +61-8-8222-5116. Fax +61-8-8232-4207
E-mail guyw@surf.net.au

South Pacific Underwater Medicine Society Annual Scientific Meeting
Palau May 8th-17th 1998

The Guest Speakers at this years meeting are **Professor David Elliott** (UK) and **Dr John Bevan** (UK). The Convener of the Annual Scientific Meeting is Dr Chris Acott.

The theme of this year's meeting is "**Highlights from the History of Diving and Diving Medicine"** and this year's workshop theme is **"The Ageing Diver".**

Those wishing to present papers are asked to contact:

Dr Chris Acott
Hyperbaric Medicine Unit, Royal Adelaide Hospital,
North Terrace, Adelaide, South Australia 5000
Telephone +61-8-8222-5116
Fax +61-8-8232-4207
E-mail guyw@surf.net.au

Intending speakers are reminded that it is SPUMS policy that speakers at the ASM must provide the printed text of their paper, and the paper on disc, to the Convener before their presentation .

The Official Travel Agent for the meeting is:

Allways Dive Expeditions,
168 High Street,
Ashburton, Victoria, Australia 3147
Telephone 03-9885-8863
Toll Free 1-800-338-239
Fax 03-9885-1164
E-mail wetworld@netlink.com.au

LETTERS TO THE EDITOR

IN-WATER RECOMPRESSION

Ichthyology Collection
B P Bishop Museum
1525 Bernice Street
Honolulu
Hawaii 96817, USA
29/7/97

Dear Editor

I thoroughly enjoyed the article[1] by Dr Elliott in the June 1997 issue of the SPUMS Journal, concerning the treatment of decompression illness following mixed gas recreational dives. Dr Elliott states that "in-water recompression using only compressed air is generally thought to have worsened more cases than it has cured" (p 92). I completely agree, this belief does, indeed, seem to be generally held by many hyperbaric medical specialists. What eludes me, however, is upon what evidence this general belief is based.

Farm, Hayashi and Beckman[2] surveyed diving fishermen in Hawaii and gathered information on incidents of in-water recompression (IWR) performed in response to symptoms of decompression illness (DCI). Of the 527 cases of IWR, all of which were performed with compressed air (Hayashi EM, personal communication 1994), 462 (87.7%) were deemed "successful" (i.e. no perceivable DCI symptoms after IWR), 51 (9.7%) resulted in detectable improvement but with mild residuals and the remaining 14 (2.7%) involved "incomplete recovery" such that the divers sought subsequent treatment in a hyperbaric facility. In my own review of published and unpublished cases of IWR (pages 154-169), 81 of the 86 cases were performed using only compressed air. Of these, 45 (56%) resulted in no detectable symptoms, 27 (33%) resulted in clear reduction of symptoms, 5 (6%) yielded ambiguous outcomes and only 4 cases (5%) involved detrimental outcomes. Only two cases involved exacerbation of symptoms, the other two divers never returned to the boat and the causes of their deaths are unknown. Even if the ambiguous cases are combined with the detrimental outcomes, these numbers hardly support the conclusion that air-only IWR has worsened more cases than it has cured. Moreover, in my informal interviews with diving fishermen in Hawaii and elsewhere, I have found that most of these divers have performed air-only IWR as a routine part of their profession (conservatively several hundred cases) with overwhelming success.

I want to make it clear that I do not advocate the use of air as a breathing gas to perform IWR. Indeed, in our review article on this subject,[3] Dr Youngblood and I adamantly discourage this practice. The advantages of breathing oxygen in response to DCS symptoms (whether on the surface or underwater) are undeniable. Our position is that if divers will ever consider attempting IWR, the proper equipment and protocol should be established in advance. However, if we are to assess the value of immediate recompression in response to the onset of DCI symptoms (regardless of breathing mixture) accurately, we need to maintain an honest and accurate perspective on the practical experience revealed by actual IWR cases. If a substantial record of detrimental outcomes to air-only IWR exists, I would genuinely want to be made aware of it. If not, perhaps it is time for the hyperbaric medical community to re-evaluate its beliefs on this particular issue.

Richard L. Pyle
Collections Technician

References

1 Elliott D. Treatment of decompression illness following mixed gas recreational dives. *SPUMS J* 1997; 27 (2): 90-95
2 Farm FP, Hayashi EM and Beckman EL. *Diving and decompression sickness treatment practices among Hawaii's diving fishermen*. Sea Grant Technical Paper UNIHI-SEAGRANT-TP-86-01. Honolulu: Sea Grant, 1986
3 Pyle RL and Youngblood DA. The case for in-water recompression. *AquaCorps J* 1995; (11): 35-46

Key Words
Air, decompression illness, immersion, treatment.

DIVING MEDICAL EDUCATION IN THE COOK ISLANDS

40 Luckens Road
West Harbour
Auckland
New Zealand
30/6/97

To all SPUMS members and interested parties

Dear Editor

SPUMS NZ has been contacted about a diving related death of a pearl diver in the Northern Group of Cook Islands. Medical advice to the diver and support personnel at the accident was provided via phone to Rarotonga by a doctor untrained in diving medicine.

It has been proposed that a suitable person, or group, travel to the Cook Islands and hold a series of seminars or other teaching sessions with doctors, nurses and divers in Rarotonga, to provide education about diving accidents and their management. We hope that some funding will be provided by the Cook Islands government or pearl farm owners. Apparently the Cook Islands are an amazing part of the world, the Northern Group especially, and the diving is supposed to be wonderful! If anyone is interested in helping to organise this, or to go and educate, please contact either Dr Michael Kluger, the Chairman of the NZ Chapter of SPUMS, (Phone NZ 09-307-7440, fax NZ 09-307-2814, e-mail m.kluger@xtra.co.nz.) or myself (Phone NZ 09-416-8541, fax 9-416-8543).

Lyndsae Wheen
Secretary, NZ Chapter of SPUMS

Key Words
Safety, training, underwater medicine.

MEDICAL EXAMINATIONS AND CERTIFICATES FOR WORKING DIVERS

Division of Workplace Health and Safety
Department of Training and Industrial Relations
PO Box 820, Lutwyche
Queensland 4030
22/8/97

Dear Editor

Enclosed is an information sheet, SAFETY LINK, Medical Examination for Underwater Divers, Information for Doctors.

This information relates to the Workplace Health and Safety compliance standard for underwater diving work which took total effect in Queensland on 2 July 1997.

Instances have been observed where working divers have not been provided with a certificate providing the necessary information, not been subjected to the examination as required in accordance with the Australian Standard AS 2299-1992 and have not been examined by an appropriate medical practitioner.

It would be appreciated if the information could be published.*

Brian Marfleet
Workplace Health and Safety Inspector

Key Words
Diving medicals, standards.

* *See pages 135-137*

ROYAL ADELAIDE HOSPITAL HYPERBARIC MEDICINE UNIT

Basic Course in Diving Medicine

Content Concentrates on the assessment of fitness of candidates for diving. HSE-approved course
Dates Monday 3/11/97 to Friday 7/11/97
Cost $A 750.00

Advanced Course in Diving and Hyperbaric Medicine

Content Discusses the diving-related, and other emergency indications for hyperbaric therapy.
Dates Monday 10/11/97 to Friday 14/11/97
Cost $A 750.00

$A 1,300.00 for both courses

Diving Medical Technicians Course

Unit 1 St John Ambulance Occupational First Aid Course. Cost approximately $A 500
Unit 2 Diving Medicine Lectures. Cost $A 500
Unit 3 Casualty Paramedical Training. Cost $A 300

Dates
October/November 1997

Unit 1	20/10/97	to	24/10/97
Unit 2	27/10/97	to	31/10/97
Unit 3	20/10/97	to	7/11/97

Diver Medical Technician Refresher Courses

Dates
27/10/97-31/10/97
Cost $A 350

For further information or to enrol contact
Professor John Williamson, Director, HMU,
Royal Adelaide Hospital,
North Terrace,South Australia, 5000.
Telephone Australia (08) 8222 5116
Overseas 61 8 8224 5116
Fax Australia (08) 8232 4207
Overseas 61 8 8232 4207

ROYAL AUSTRALIAN NAVY

MEDICAL OFFICERS UNDERWATER MEDICINE COURSE 1996

Monday 24/11/97 to Friday 5/12/97

Apply directly to
The Officer in Charge, Submarine and Underwater Medicine Unit
HMAS PENGUIN
Middle Head Road, Mosman, New South Wales 2088
Telephone (02) 9960 0572 Fax (02) 9960 4435

BOOK REVIEWS

SOLO DIVING.
Robert Von Maier.
Watersport Publishing Inc. PO Box 83727, San Diego, California. 92138, USA.
Price from the publishers $US 12.95. Postage and packing extra. Credit card orders may be placed by phone on +1-619-697-0703.

Key Words
Safety, solo diving.

Diving with a buddy has long been the tenet of the various training agencies, ostensibly to make those people who are inherently insecure in the water feel safer. We know that often these buddies see each other only on entry into and exit from the water and it is these buddies who let the system down. However, until every scuba diver is fitted with through water communications to his companions, both in and out of the water, then all scuba divers are essentially solo divers.

We have all seen the dive master of the day wander round a dive boat arbitrarily selecting buddy pairs whom we know to have vastly different skill levels. Does the experienced diver, with say 500 dives under his belt, increase his safety if he is paired with a novice who has just finished his, or her, "advanced" course and has done 10 dives?

Von Maier has written this book is to encourage every diver to become self-sufficient so that, if left alone for any reason, he or she will be able to cope with the situation. The author is not advocating that all divers dive alone, far from it. In this book he is questioning the blind adherence to one of the earliest platforms of the instruction agencies, that if you are diving with a companion you are less likely to get into trouble. If this is so, why do divers continue to die?

Ideally, the buddy system should match two divers of comparable skill and experience levels who share the same interests, maintain a constant vigilance over each other and their gauges before, during and after the dive and always remain in close contact with each other should immediate assistance be required. In 40 years of diving I have never seen this happen. There are some dives where the depth and nature of the dive prohibits all but the few very experienced divers, for which it is very difficult to find an appropriately skilled and experienced buddy, so that it may be more prudent to do the dive solo.

To be a self-sufficient diver von Maier advocates that the diver needs to have better than average water fitness, be self critical and be able to assess both the conditions and his own physical abilities, skills, training and experience to make each dive a safe one. Perhaps, most importantly, the diver must know his own limitations.

In chapter 4 on Dive Management Guidelines the author promulgates two rules. Firstly *Never solo dive deeper than twice the depth to which you can free dive.* Secondly *A solo diver's underwater distance from the point of exit should not exceed the distance he can comfortably and easily swim, equipped with full scuba gear, on the surface.* To these one should add Neumann's First Law of Diving: *Always dive with air in your tank.* I have no problems with any of this. I also strongly agree with the author's statement on page 48; "One's competency and proficiency as a self-sufficient diver are directly proportional to one's free diving abilities." "A good breath-hold diver has a better chance of becoming a competent scuba diver than a person whose free diving skills are lacking." The chapter continues with a discussion on air management, how to calculate rates of air consumption, thermal protection and buoyancy control.

Chapter 5 then discusses alternative ways of complying with Neumann's First Law of always having a gas supply. He mentions alternative air sources (which, in the American idiom, he insists on calling alternate) such as the octopus regulator should the primary regulator fail, double tanks with a manifold and redundant supplies such as the Spare Air or a pony bottle.

Chapter 6 is an anthology of personal opinions on solo diving from a number of "names" in the scuba diving world, not all of whom I respect or hold in very high regard. Then follows a glossary of diving terms, which I feel is rather unnecessary in a book of this nature.

I agree with the author that every diver should be self-sufficient, be responsible for his own equipment and actions and be able to extricate himself from any untoward circumstance without having to rely on another diver. Sharing a dive with a buddy can make that dive much more enjoyable, but the lack of a buddy should not necessarily preclude any dive.

The book is small, quick and easy to read with a chatty but highly opinionated style. It does not provide a step by step guide to solo diving or, more appropriately, self sufficient diving but it does call into question the belief that buddy diving is, by definition, safer. It is a book that should be read by all experienced divers but not all these divers should follow the practice. There are some "divers" who should not be allowed in the water, let alone dive solo.

David Davies

Key Words
Safety, solo diving.

COLD WATER DIVING - A GUIDE TO ICE DIVING.
John N Heine.
Best Publishing Company, P.O.Box 30100, Flagstaff, Arizona 86003-0100, USA.
Price from the publishers $US 17.95. Postage and packing extra. Credit card orders may be placed by phone on +1-520-527-1055 or faxed to +1-520-526-0370.

Few divers in the South Pacific region get an opportunity to dive in *really* cold water and, unfortunately, spectacular under-ice vistas will remain only an "armchair experience" for most readers of this journal. Nonetheless, ice diving is possible in a few highland lakes in southern Australia and New Zealand. For those lucky enough to dive in such settings, this small book provides an excellent introduction. For other readers, its copious, high-quality colour photographs (121 photos in 127 pages) can serve as a window into an inherently interesting field of human activity.

The author, John Heine, is certainly well experienced in this field, having dived extensively in cold and under-ice conditions in Alaska, Antarctica and various lakes in the Rocky Mountains. He is the Diving Safety Officer for Moss Landing Marine Laboratories at California State University and is currently President of the American Academy of Underwater Sciences. He is also certified as an Ice Diving Specialty Instructor. As such, he is ideally placed to write an up-to-date guide on the topic of cold water diving.

In 1973 NAUI first published a small, but extremely useful, book entitled "Cold weather and under ice scuba diving" by Lee Somers, from the University of Michigan. The need for subsequent reprints of this monograph up until quite recent years, demonstrates a continuing requirement, from both scientific and recreational divers, for a practical guidebook in this field. However, technical advances during the intervening couple of decades have rendered obsolete certain sections of Somers' book. This new work by John Heine not only corrects any such shortfalls, but offers a number of valuable new insights.

The book appears to have been designed as a training manual for ice diving courses. However, it wisely starts with the warning "This book is not a substitute for scuba diving or ice diving instruction. You must be certified for diving in cold water and under ice" (I am not sure whether the pun is intended!). There are chapters on the cold water environment, training, equipment, ice diving operations including preparation of the ice-hole, and safety and emergency procedures. Most of the text is excellent, with plenty of good, sound, practical advice. Medical aspects are touched on, with about 14 half-pages (the other half of each page being photographs) devoted to topics such as frostbite, hypothermia, management of heat loss victims, the unconscious diver, and what is curiously listed as "conscious diver with lung overpressure or DCI". While these medical sections may be considered as adequate, they are perhaps the weakest section of the book.

If I were to offer any other criticism of the text it would be directed at the author's literary style, rather than at the information he presents. For example, as previously mentioned, the book is generously illustrated with a range of excellent colour photographs, but these are somewhat diminished by the banality of the accompanying captions. A random selection came up with the following gems of what Basil Fawlty would scathingly call "the bleeding obvious": "Cold, wet divers can become hypothermic in cold weather conditions"; "The tether line is the route back to the dive hole in low visibility conditions"; and "Diving from small boats in ice conditions requires careful attention to environmental conditions". All undeniably true, but perhaps a touch irritating in their over-simplification.

This minor quibble aside, "Cold Water Diving" is a highly useful, up-to-date and practical guide. It makes stimulating reading for anyone interested in the general field of diving, and should be considered essential for any adventurous soul even contemplating taking up ice diving.

Peter Sullivan
Australian Antarctic Division

Key Words
Accidents, environment, thermal problems, safety, training.

SPUMS ANNUAL SCIENTIFIC MEETING 1996

"NO TECH" TECHNICAL DIVING: THE LOBSTER DIVERS OF LA MOSQUITIA

Tom Millington

Key Words

Deaths, deep diving, decompression illness, equipment, occupational diving, treatment.

La Mosquitia includes the south eastern area of Honduras, and the north eastern area of Nicaragua. This area is extremely remote, with no access except by boat or plane. The land is rain forest and savannahs, traversed by many rivers which meander to the Atlantic.

The population of La Mosquitia in Honduras is about 40,000, with the majority of the people belonging to the Miskito Indian tribe. The main source of income for the entire population is lobster diving. Alternative income is derived from fishing and a minimal amount of agriculture. In Nicaragua turtles are fished for local consumption legally, but none can be sold outside the area. There is no tourism in La Mosquitia, but the potential for an "eco-tourist" industry is unlimited.

The lobster fishery started in the early 1960s and was exclusively free-diving. The lobsters were sold to the processing plants which are in the Bay Islands of Roatan and Guanaja. By the late 1970s lobster could not be found shallow enough for free diving and the lobster boats out of Roatan and Guanaja began supplying the Miskito divers with tanks and masks to take lobster. They had no knowledge of diving physiology or safety and they began to dive deeper to find the lobster. By the early 1980s, dives to 27 to 33 m (90 to 110 feet) were commonplace. The total number of dives a day would be from 9 to 20.

Originally the divers learned to dive by observing other divers. The boat captains supplied marijuana and rum to the divers before each dive, as it would "Help them to see the lobster better". If a diver returned to the boat with paralysis, it was thought that he had the mermaid's curse on him. If he survived to the mainland, he was often taken to a witch doctor or herbal doctor. When he finally make it to one of the chambers, there was the added delay, plus possible complications from the treatments of the witch doctor.

Many paralysed Miskito divers are being treated at the Episcopalian clinic at Anthony's Key Resort in Roatan, where a 54 inch (1.37 m) deck decompression chamber was donated to the island in the late 1980s. As of 1995 around 1,000 divers have been treated in this chamber, with 90% of the treatments being given to Miskito Indians.

A Moravian church clinic in Ahuas, a small village about 40 km (25 miles) inland, was also being inundated with paralysed divers. The director of the clinic contacted me in 1989. Los Robles Regional Medical Center in Thousand Oaks, California, donated an old Vickers monoplace chamber to the Clinica Evangelica Moravia in Ahuas in 1991. Since that time well over 200 Miskito divers have been treated in this chamber.

The average delay to treatment is about 5 to 7 days. Approximately 70% of the divers have severe decompression illness (DCI), with paraplegia or quadriplegia as their presenting symptoms. Another 20 to 25% present with moderate symptoms, including bladder dysfunction, paraesthesias and weakness in the extremities, ataxia, and pain. The remaining few are mild cases.

In spite of the delay to treatment, the severity of the cases and the limitations of the old monoplace chamber, statistics from the clinic show about 65% of the divers respond with good to excellent outcomes, 20% fair outcomes, and only 10 to 15% with poor or no response. Unfortunately, no neuropsychological or neuro-imaging tests are able to the done on these divers.

Examinations have been performed on "normal" lobster divers which reveal abnormal neurological findings in all those examined. It is felt that virtually 100% of the diving population has at least a mild form of decompression sickness. It has been estimated that one or two divers on each boat develops severe DCI. The total number of deaths in the diving population is not well documented, but it is not uncommon to have deaths from shark attacks, air embolism, out of air events and probably carbon monoxide (CO) contaminated air.

Those divers who have not been treated in the chambers, or who have had poor responses, are often abandoned by their wives and die within four years from kidney infections secondary to self catheterisation, or from infected bedsores (decubitus ulcers). Their wives frequently turn to prostitution to provide a living for their children, and the incidence of sexually transmitted disease is on the increase. This is a tragedy which involves the entire population of La Mosquitia.

As an outgrowth of articles written about this problem, others have become touched by this situation, including Bob Izdepski, the editor of *The Universal Diver*. He has written articles in this newspaper about the appalling situation in La Mosquitia, which have stimulated others in the commercial diving industry to offer aid.

CalDive has donated a 48 inch (1.2 m) recompression chamber for La Mosquitia. Bob Armington, a retired commercial diver, moved to the area and opened up a diving school for the Miskito Indians, funded by the Moravian Church, and the association of lobster dive boats in Guanaja. A non-profit organization has been started by Bob Izdepski called SOS (Sub Ocean Safety) which is accepting donations of both material and money to continue working towards helping with the diving problem in La Mosquitia.

So far SOS has filmed a video concerning in-water recompression to be utilised in the diving schools, and transported the 48 inch (1.2 m) chamber to a coastal clinic in La Mosquitia. A compressor has been donated by Oceaneering, and DAN (Divers Alert Network) has donated $2,000 US to SOS. These funds were used to rebuild a Lister engine to drive the compressor. The physician at the clinic will be instructed in diving and hyperbaric medicine by the three diving medicine specialists with SOS, Dr David Youngblood, Dr Keith VanMeter and myself.

Members of SOS have been researching the statistics of the lobster industry in Honduras. There were a total of 262 lobster boats in the Bay Islands, 70 of which dive for lobster, and the rest trap lobster. The average lobster diver makes about $US9 a day, although many do much better. The trips last about two weeks, and they can make as much as $US750 on a good trip.

In the last two years, the skippers have been teaching the divers about the proper size of lobsters and this year less than 5% of the take are undersized. Their project for the next season is to make sure females with eggs are not taken.

The government has imposed a four month ban on lobster fishing the last two years, and the net yield of lobster last year has been the highest in the past decade.

If a diver is paralysed, the lobster boat owner must pay him, for a year, the amount of money the diver made the day before he was injured. If the diver has not recovered, the boat owner must pay a "death settlement", which is equivalent to three years' wages.

For this reason, as well as not wanting to be responsible for another human being's death, the organization of lobster dive boat owners has written a list of standards, which they have asked the Ministry of Fishing to make as law. These standards include having clean filters on the boat's compressors; separation of the compressor's exhaust from the air intake; tank inspections every third trip; oxygen on each boat with a face mask to deliver the oxygen to an injured diver; divers to have their own depth gauge and pressure gauge (which they do not use now); every boat utilising at least four trained divers (600 of the estimated 5000 divers will have been trained by July 1996); a 3 mm (1/8 inch) or equivalent short type of wet suit.

They would also like to have every skipper take a week's "crash" course on diving, so the skippers have some idea of what the divers are doing. The skippers and the instructors at the dive school are urging the divers to stop using rum and marijuana before their dives. Tobacco and rum are used in La Mosquitia from childhood and it is taking a large effort to decrease their use of these.

Plans are being formulated for several studies on the long term effects of untreated decompression sickness from both a physical and a neuropsychological standpoint using the large population of divers from La Mosquitia as well as several other Caribbean islands where the same problems exist. A second study is planned using the many injured divers presenting on each boat. We are contemplating using on-the-site treatment of injured divers, alternating in-water oxygen recompression therapy using the Australian tables, versus emergency treatment with oxygen in a portable 2 ATA chamber which will also be on the boat. After initial emergency treatment, the divers will receive standard recompression therapy at the main chamber in the nearest clinic. Statistics will be kept to see which is the most effective treatment, on site surface oxygen, in-water oxygen recompression, or emergency 2 ATA chamber oxygen.

Similar problems are occurring in many other areas of the Caribbean, as well as many other third world areas where the lure of money outweighs the significant risk from DCI in untrained divers and uncaring boat operators. Hopefully the work of Sub Ocean Safety and other interested groups can continue to make a positive impact on these areas in the future.

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ROUND WINDOW MEMBRANE RUPTURE IN SCUBA DIVERS

Noel Roydhouse

Summary

Since 1971 the author has examined 19 cases of round window membrane (RWM) rupture and one case of oval window rupture caused by scuba diving. They consisted of 8 cases operated on and in which flow of perilymph was seen (Group A), 2 cases operated on and an intact RWM and oval window annular ligament (OWAL) were seen

(Group B), 6 cases in whom the diagnosis was solely on clinical grounds with no operation (Group C) and a group of 4 cases treated by other surgeons but examined for a follow up or second opinion (Group D). The average follow-up period for the 4 groups are 6.9, 10.5, 11.6 and 5.5 years respectively. Three patients have been followed for over 20 years. The symptoms for each group are given. Group C symptoms were worse than the other groups which offers support for the diagnosis. The follow-up allows comparison of initial with final audiograms and the post-treatment years of further diving. The operated cases appear to have a better prognosis, however the return to diving in all groups did not result in a relapse. Two case histories and a brief comment on the causation is given.

Key words

Barotrauma, ENT, injury, recreational diving, treatment.

Introduction

The popularity of scuba diving continues to increase and accordingly there is an increasing number of scuba diving accidents, injuries or adverse incidents. The more common and alarming are those cases with labyrinthine symptoms, with or without deafness. Vestibular labyrinthine symptoms include loss of balance, vertigo and dizziness. Vertigo is defined as a spinning or rotary sensation but also includes oscillopsia, a vertical or horizontal hallucinatory movement. Labyrinthine dizziness is more than just non-specific dizziness. It is more severe, associated with one or more of loss of balance, disorientation, nausea or vomiting. In a series of 1,110 divers who consulted me for their scuba diving problems, 203 fitted in to this category but did include 1 case of non-diving round window membrane (RWM) rupture (Table 1).

TABLE 1

203 CASES WITH VESTIBULAR LABYRINTHINE SYMPTOMS

Cases with deafness	72
Cases without deafness	112
Ruptured eardrums	19
Total	203
Subgroup	
Ruptured window membrane	20

A subgroup of these are the 19 divers with a rupture of the RWM and one of OWAL. Goodhill[1] described 13 cases of round window fistula including 1 scuba diver, whilst Edmonds et al.[2] reported on 6 round window fistulas in naval divers. Rolland and Walsh[3] described 1,200 cases of repair to the round window and 20 cases of fistula of the oval window from 1989 to 1993. They included an unstated number of cases where scuba diving was a factor. Their overall failure rate was 24% but since 1990 it has been 3.1%

Symptomatology

The 20 cases were divided into 4 groups depending on presentation and treatment. Group A (Cases 1-8) were those seen by the author and diagnosis was confirmed at operation by viewing perilymph outflow. Case 4 had no deafness until 24 hours after the dive which increased the next day. Case 7 had no RWM at all with vertigo continuing for 3 days and a steady level 65 db loss. He was operated on after 2 days of medical treatment. Group B (Cases 9-10) were the 2 patients in whom no outflow was seen at operation. In case 9 the RWM was seen to bulge within 5 seconds of compressing the neck veins. It also had a heterogenous appearance compared with a normal membrane, suggestive of a healed rupture.

Group C (Cases 11-16) were those diagnosed as RWM rupture but for one reason or another were not operated on. It is known that some cases resolve spontaneously or heal without operation. All patients suspected of having a fistula were given medical treatment for at least 4 days before deciding on an operation. This period was shortened if there is a positive fistula sign or increasing severity of the signs and symptoms.

Table 2 (page 150) shows that Group C had generally worse symptoms than groups A and B, apart from Case 12 who denied any form of dizziness or vertigo. He had a deafness averaging 70 db across the whole frequency range except for a loss of 25 db at 500 Hz. It had been worsening progressively for 3 days. He responded immediately to bed rest, prednisone, oxpentifylline and chlorothiazide, the routine form of treatment. Oxygen therapy was also given to those admitted to hospital.

Group D were the 4 cases operated on by other surgeons but seen for a second opinion. Table 3 (page 140) shows the end results of groups A to D.

Discussion

Cases that were personally treated were counselled on the effect of further diving. Of the first 16 cases (Groups A, B and C) 12 had a history of difficulty in clearing their ears on descent and 2 of these were recovering from a cold and ten made a fast descent or ascent or both. Safe diving practices were stressed and only 4 gave up immediately and 2 were lost to follow-up. The reasons for giving up were: frightened off diving (2) and gave up voluntarily (2). No

TABLE 2

COMPARISON OF MAJOR SYMPTOMS OF 3 GROUPS (16 CASES) RELATED TO END OF DIVE

	Group A (Cases 1-8)	Group B (Cases 9-10)	Group C (Cases 11-16)
Adverse clearing pressure	6	1	5
Onset of first symptom	-1 minute to 2 hours	5 minutes	-2 minutes to 1 minute
Modal	0 minutes	5 minutes	0 minutes
Labyrinthine symptom onset	-1 minute to 3 days	1 day	-2 minutes to 7 days
Modal	2 hours	1 day	5 min
Vertigo	4 hours	1 day	6 minutes
Off balance	4 hours	1 day	1 minutes
Longest duration	3 days	3 months	5 days
Deafness			
Onset	1 minute to 24 hours	5 minutes	1 minute to 7 days
*db loss modal (number of cases)	55 (4)	70 (2)	90 (3)
Tinnitus			
Onset	1 minute to 2 days	5 minutes	0 minutes to 24 hours
Severity (1 to 5, mild to severe)	1-4	1	1-4

* Average of 3 worst frequencies of a 6 frequency audiogram

diver was forbidden to dive but they were told to telephone the author reverse charges (collect) from anywhere, if their problem recurred. There have been no recurrences.

An interesting case is not listed here because her RWM rupture occurred in a road traffic accident 3 weeks before she went diving. She dived uneventfully but reported 3 days later with vertigo. She eventually underwent repair at consecutive operations of both RWM rupture and OWAL rupture. She later became a diving instructor and, when last contacted in 1994, had continued diving for 14 years and was off on a diving holiday to Australia.

TABLE 3

END RESULTS GROUPS A TO D

	Group A (Cases1-8)	Group B (Cases 9-10)	Group C (Cases 11-16)	Group D (Cases 17-20)
Years of follow up	0 to 21	1 and 20	2 to 23	0 to 16
Average	6 to 7	10.5	11.6	5.5
National Acoustic Laboratory (NAL), Australia: percentage hearing handicap				
Pre-treatment average	11.55	13.25	11.85	
Last follow up average	1.40	13.75	1.78	
Known years of diving since diagnosis	1, 1, 13, 2, 14	1, 20	3, 6, 16, 18, 23	1, 5, 16
No further diving or no follow-up	3	0	1	1

Case Histories

CASE 2

He was diving on holiday and came up with a feeling of pressure in his right ear. He did have some difficulty in clearing his ear. On surfacing he noted a ringing in his ears and some deafness. The deafness went away after 2 weeks but came back 2 days later and remained. The tinnitus increased and stayed stable with his deafness. Dizziness had been noted after the dive with nausea and loss of balance which lasted for 36 hours. He was a fisherman and for the month after his dive he had been carrying 50 kg baskets of fish daily.

At examination he had a positive fistula sign and said that objects "rocked from side to side." RWM repair was carried out 6 weeks after the dive. No improvement in hearing was obtained. He was back diving within a year and 13 years later his hearing had not deteriorated further.

CASE 7

This was complicated by cerebral decompression illness after a dive, on February 15th, 1995, to 39 m. When his memory returned he was in a country hospital from which he was discharged on February 17th. He was then aware of a loss of balance and right deafness. He developed vertigo with the spinning sensation to the right, when he sat up or moved quickly. He had a minor positive fistula sign (a little light headed) and flat 65 db audiogram loss. At operation there was no RWM. It was repaired with perichondrium. His audiogram four months later was normal apart from 30 db loss at 4, 6 and 8 KHz.

He wanted to go back diving and has been lost to follow up.

Conclusion

The message is that after a careful and probably radical repair operation of a RWM rupture the diver can return to diving. There is one proviso and that is that knowledgeable and detailed information is provided in a counselling session to the diver, preferably by a scuba diving ear surgeon. Forceful inflation of the ears should not continue for more than 5 seconds at a time and all safe diving practices should be adhered to. The series of 20 cases is small compared to Rolland and Walsh[3] but it is possible that the cause of these ruptures in divers is different from the usual land-based ruptures. Molvær[4] hypothesises that the inner ear damage is caused by expansion on ascent of an air bubble which gains access to the inner ear through the ruptured window membrane. This seems unlikely as any rise in inner ear pressure could be vented out through the fistula. Rolland[3] considers that the majority of land based ruptures occur in a weakened membrane. If this is so, after a repair there is no remaining pre-existing cause.

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FACTORS AFFECTING REBREATHER PERFORMANCE

R W (Bill) Hamilton

Key Words

Equipment, rebreathing.

Breathing resistance

Work of breathing is important in rebreathers; as depth, and hence gas density, increase it can provide limitation to some systems. Tubing and hose diameters, corners, etc. become very important in rebreathers designed for deep use.

The location of the counterlung relative to the diver's lungs has a big impact on the effort of breathing. If the counterlung is above the diver's lungs the differential pressure (static lung loading) is negative and the diver has to make an extra effort to inspire. On the other hand if the breathing bag is below the diver's lungs there is a positive pressure delivered to the lungs; this requires an expiratory effort and can tend to force gas out around the seal of a full-face mask. An effective compromise is an over-the-shoulder style, or better yet a counterlung more or less wrapped round the chest. Some units use a bellows type bag with a counterweight to balance the differential pressure.[1] This reduces the negative pressure when the diver is prone and adds a negative pressure component when supine: it has little effect when the diver is upright or on her side, where little help is needed. Static lung loading is essentially independent of depth, but as gas density increases the work of breathing it can increase in relevance.

Scrubbers and scrubbing CO_2

Although the function of the scrubber canister is straightforward, the chemistry is slightly complex. The absorption of carbon dioxide by an alkaline metal hydroxide takes place in several steps; the alkaline metals may be one or more of sodium, calcium and lithium. Water vapour is necessary to start the reaction and ultimately the water is returned. Carbon dioxide ends up being converted to carbonates of the alkaline metals, such as sodium carbonate.

Considerable engineering goes into the design of a scrubber canister. It has to be an engineering trade off of several factors, including resistance, channelling, protection against water entry and cold effects. Gas flow through the canister should impose minimal resistance, but if the path is too short and the gas goes through too quickly (short dwell time) then it may not have long enough time to react. If the material settles and leaves areas with lower resistance the gas will go preferentially through the paths of least resistance and will exhausts the absorbent near the easy paths but miss the rest of it, known as channelling. Baffles, packing springs and other tricks are used to maintain an even packing density (hence resistance) and reduce channelling. Another trade off is that of particle size. Larger particles cause less resistance, but the surface area for exchange is less than with smaller particles; the smaller particles have higher resistance. Ways of dealing with this include constructing the particles to have more surface area and to pick the best combination of path length and cross-section for the granule size.

There is a wide variety of scrubber designs and a choice of several scrubber materials. Scrubber design can be a lifetime engineering speciality. [1,2] The material in Volume 2 of the US Navy Diving Manual on the Mk 15/16 system is invaluable to anyone contemplating designing or using a rebreather.[3]

The effect of cold on CO_2 absorbents

A major problem is the function of the scrubber when the diver is in cold water. Soda lime loses much of its appetite for CO_2 when cold. This can reduce the duration to a fraction of its endurance when warm. Countermeasures to cold degradation of scrubber performance include insulation of the scrubber and hoses, active warming with hot water or electrical or chemical heat and the use of lithium hydroxide (which works better than soda lime when cold but is much more caustic). For reasons not fully understood a scrubber does not work as well at greater depths.

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This short paper has been constructed from what had to be removed, for space reasons, from Dr Hamilton's paper REBREATHER PHYSIOLOGY, published SPUMS J 1997; 27 (1): 57-60.

Continued from page 180

Results

A multi-disciplinary approach has resulted whereby 17 case which initial approach could not be explained were resolved with credible scientific explanation.

Conclusions

In fatal diving accidents it has to be recognised that it is not only the medical experts, but a team of technicians, engineers and scientists who are able to reach a logical and, perhaps more importantly, a legally defensible position.

From

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Key Words

Accidents, deaths, investigations.

ARTICLES OF INTEREST REPRINTED FROM OTHER JOURNALS

ASSUME THE RISK AND TAKE THE BLAME

Bob Halstead

Key Words
Environment, recreational diving, risk, safety.

I am not fond of flying. As I strap in, my usually serene mental state is disturbed by niggling doubts:- will the wings fall off? didn't the pilot look drunk? why are the ground crew kicking the tyres? Only by serious mental discipline can I overcome this paranoia, resign myself to my fate and get secured for the take-off.

When I strap on scuba and prepare to dive, a different set of thoughts are set in motion. Am I feeling OK?, do I have the skills, knowledge and equipment necessary to overcome the risk of this dive to make it safe for me? If I am diving with someone else, my buddy, will he or she decrease or increase the risk of the dive?

I am hoping the divemaster will provide some information that can help me determine the risk for this particular dive, such as a map of the site with depths indicated and possible currents and peculiar hazards described. Also useful would be popular dive plans, distinctive features for navigation and a description of interesting marine life. This will assist me in creating a dive plan that is safe **for me,** taking into account my particular experience and abilities. Only I can do that, not the divemaster nor anyone else.

But the divemaster has not provided me with any useful information about the dive site as he is too busy telling everyone "not" - not to leave their buddy, not to go deeper than 18 m, not to make a decompression dive, not to touch anything, not to surface without making a safety stop, not to get back on the boat with less than one quarter of a tank of air remaining and not to stay underwater for more than forty minutes. He is worried that he might be blamed if a problem occurs. Ironically he is actually making the dive less safe by spouting rules instead of giving local information.

A scuba dive involves **active** participation while an aircraft ride involves **passive** participation. For the aircraft ride if something goes wrong I feel I have a right to blame someone, but for the Scuba dive, if anything goes wrong it is **my** fault. I do not have "rights", I have "responsibilities". I like diving more than flying because I have control. I can even choose not to dive if I do not like the look of the dive site and if I do something wrong I blame **myself** and apologise to the divemaster.

The sport of diving has shown itself to be responsible in that, from its earliest days, certification courses were created so that budding divers could learn how to survive underwater. I have always been a great believer in NAUI's marvellous creed "Safety through Education", note this is Education not Regulation. Few, if any, other sports have anything like the complex system of certification courses that diving has nor require certification before participation. Anyone can choose to climb Mount Everest, or ski down it, but to go diving you need certification and, guess what, **we** did this, **not** any Government.

But what does this certification mean if divemasters ignore it and proceed to spout a litany of rules before every dive? Surely certification is meant to signify a level of competence and bestows responsibility on the diver. The dive master can offer reminders, particularly to the inexperienced, fair enough, but the divemaster's job is to provide local knowledge that will assist the diver to plan the dive, and organise for rescues in case the diver makes a mistake. They are not there to take responsibility for the mistake, **even** if the information they have given is inaccurate.

Our certification courses are appropriate for the activities they are intended for, but divers must recognise they are limited by their training and experience. Some recently certified Openwater divers immediately imagine they are qualified for Commercial diving. The one **big** difference they all ignore is that, for Construction (Commercial) diving, **the risk is determined by the job**.

Which is why I have the utmost respect for Construction divers who have to dive in the most appalling conditions, but, with Recreational diving, **the risk is chosen by the diver.** Divers can choose to dive deep or shallow, to stay near the boat or swim a distance away. They can even choose NOT to dive if the conditions are poor.

As a passive, paying passenger in an aircraft, if the airline screws up, and I get injured, then they have breached their duty of care and they should pay for it. Diving is fundamentally different. I might be prepared to demand compensation if the boat sank on the way to the dive site while I am still a passive passenger but, once I am diving, I am my own responsibility. It cannot be any other way since there is no practical way for the divemaster to control me when I am underwater and no practical way for the divemaster to know my real diving ability. All he can do is inspect my diving certification, which should be enough. It is up to **me** to know my ability and to apply it appropriately in planning the dive. I am a **responsible diver**.

Unfortunately some people cannot work this out. They look for someone else to blame. They think that if a diver gets bent it must be the fault of the divemaster or boat owner or perhaps the instructor or the instructor's training organisation or perhaps the equipment manufacturer or maybe stress from work or, and this is very sad, but do you realise the diver's parents never actually had sex together. That excuses everything.

Let me make this clear, if a diver gets bent **it is his or her fault**! Not only should they suffer the pain and inconvenience and cost of the injury, they should be **fined**! (well, not really, but you get the idea). The boat owner should be able to demand compensation! Do not think that this is so outrageous, dangerous drivers of cars are fined if they have an accident, why not dangerous divers? What is more, if a diver fails to report post-dive symptoms to the divemaster resulting in delayed treatment, then the diver has to take the blame for the more severe or permanent injury which could occur. Ignorance of the law is no excuse, but (proclaimed) ignorance of the laws of diving apparently is. "The divemaster never told me I could get bent". Well I am telling everyone now, to be a safe diver you need **skills** (and good health), **knowledge**, the **right equipment** and **good luck**. If you do not have them and you get hurt then it is **your fault**.

Dangerous divers are those who attempt dives for which they do not have sufficient skills, knowledge nor the correct equipment. If they get away with it, well that is their good luck. If they do not, and get hurt, make them pay! A diving certification means **no excuses**. I am sure responsible (= **safe**) divers will cheer, and if a responsible diver gets hurt through some unpredictable event, or an admitted mistake, we can show the appropriate mercy. How many of you have had dives ruined by dangerous divers who dive beyond their ability or who make no effort to keep themselves in touch with responsible diving?

The very dangerous result of encouraging the transfer of blame from the diver to a third party (which is apparently the aim of Workplace diving legislation) is that it removes the incentive for people to become skilled at what they do. They unrealistically imagine that "the dive master will look after me." It also encourages legal action against the dive master or operator by lazy, stupid or corrupt divers after a bit of easy money. There is actual evidence of this is Queensland.

It has been said that amateurs practice until they get it right and professionals practice until they cannot get it wrong. To be a safe diver the professional approach is required and this takes time and effort. **Passive** participation in diving is just not possible. Unfortunately things **will** inevitably go wrong from time to time, even with the most experienced and well trained diver, and that is because:-

1 People make mistakes. Alas we are but human.
2 Unpredictable events occur.

Safe diving, from my personal experience, involves avoiding other divers underwater as much as possible so that I will not be troubled by their mistakes and being totally self-sufficient, with redundant systems, so that if even I make a mistake I can easily recover. I also like to know that there is someone competent looking out for me on the surface and able to rescue me if I end up away from the boat. To avoid unpredictable effects of a negative kind I worship Neptune, the occasional sacrifice of an old Nikonos camera seems to do the trick just fine!

Diving is Adventure and this implies exposure to increased risk. I wish you great adventures, just assume the risk and, if you stuff up, take the blame.

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IN-WATER RECOMPRESSION AS AN EMERGENCY FIELD TREATMENT OF DECOMPRESSION ILLNESS

Richard Pyle and David Youngblood

Abstract

In-water recompression (IWR) is defined as the practice of treating divers suffering from decompression illness (DCI) by recompression underwater after the onset of DCI symptoms. The practice of IWR has been strongly discouraged by many authors, recompression chamber operators and diving physicians. Much of the opposition to IWR is founded in the theoretical risks associated with placing a person suffering from DCI into the uncontrolled underwater environment. Evidence from available reports of attempted IWR indicates an overwhelming majority of cases in which the condition of DCI victims improved after attempted IWR. At least three formal methods of IWR have been published. All of them prescribe breathing 100% oxygen for prolonged periods of time at a depth of 9 m (30 ft), supplied using a full face mask. Many factors must be considered when determining whether IWR should be

implemented in response to the onset of DCI. The efficacy of IWR and the ideal methodology employed cannot be fully determined without more careful analysis of case histories.

Key Words

Air, decompression illness, hyperbaric oxygen, oxygen, treatment.

Introduction

There are many controversial topics within the emerging field of "technical" diving. This is not surprising, considering that technical diving activities are often high-risk in nature and extend beyond widely accepted "recreational" diving guidelines. Furthermore, many aspects of technical diving involve systems and procedures which have not yet been entirely validated by controlled experimentation or by extensive quantitative data. Seldom disputed, however, is the fact that many technical divers are conducting dives to depths well in excess of 39 m (130 ft) for bottom times which result in extensive decompression obligations, and that these more extreme dive profiles result in an increased potential for suffering from decompression illness (DCI).

Although technical diving involves sophisticated equipment and procedures designed to reduce the risk of sustaining DCI from these more extreme exposures, the risk nevertheless remains significant. Along with this increased potential for DCI comes an increased need for many "technical" divers to be aware of, and prepared for, the appropriate implementation of emergency procedures in response to DCI. In the words of Michael Menduno,[1] "The solution for the technical community is to expect and plan for DCI and be prepared to deal with it".

There is almost universal agreement on the practice of administering oxygen to divers exhibiting symptoms of DCI. This practice is strongly supported both by theoretical models of dissolved-gas physiology and by empirical evidence from DCI cases. The answer to the question of how best to treat the afflicted diver beyond the administration of oxygen, however, is not as widely agreed upon. Perhaps the most controversial topic in this area is that of in-water recompression (IWR); the practice of treating a diver suffering from DCI by placing them back underwater after the onset of DCI symptoms, using the pressure exerted by water at depth as a means of recompression.

At one extreme of this controversy is conventional conviction: divers showing signs of DCI should *never*, under *any circumstances*, be placed back in the water. As pointed out by Gilliam and Von Maier,[2] "Ask any hyperbaric expert or chamber supervisor their feelings on in-the-water recompression and you will get an almost universal recommendation against such a practice." Most diving instruction manuals condemn IWR, and the Divers Alert Network (DAN) Underwater Diving Accident and Oxygen First Aid Manual states in italicized print that "*In-water recompression should never be attempted*".[3]

On the other hand, IWR for treatment of DCI is a reality in many fields of diving professionals. Abalone divers in Australia[4,5] and diving fishermen in Hawaii[6-8] have relied on IWR for the treatment of DCI on repeated occasions. Many of these individuals walking around today might be dead or confined to a wheelchair had they not re-entered the water immediately after noticing symptoms of DCI.

At the root of the controversy surrounding this topic is a clash between theory and practice.

IWR in theory

There are many important reasons why the practice of IWR has been so adamantly discouraged. The idea of placing a person who is suffering from a potentially debilitating disorder into the harsh and uncontrollable underwater environment appears to border on lunacy. Hazards on many levels are increased with immersion and the possibility of worsening the afflicted diver's condition is substantial.

The most often cited risk of attempted IWR is the danger of adding more nitrogen to already saturated tissues. Using air or enriched air nitrox (EAN) as a breathing gas during attempted IWR may lead to an increased loading of dissolved nitrogen, causing a bad situation to become worse. Furthermore, the elevated inspired partial pressure of nitrogen while breathing such mixtures at depth leads to a reduced nitrogen gradient across alveolar membranes, slowing the rate at which dissolved nitrogen is eliminated from the blood (relative to breathing the same gas at the surface).

The underwater environment is not very conducive to the treatment of a diver suffering from DCI. Perhaps the most obvious concern is the risk of drowning. Depending on the severity of the DCI symptoms, the afflicted diver may not be able to keep a regulator securely in his or her mouth. Even if the diver is functioning nearly perfectly, the risk of drowning while underwater far exceeds the risk of drowning while resting in a boat. Another complicating factor is that communications are extremely limited underwater. Therefore, monitoring and evaluating the condition of the afflicted diver (while they are performing IWR) can be very difficult.

In almost all cases, attempts at IWR will occur in water which is colder than body temperature. Successful

IWR may require several hours of immersion, and even in tropical waters with full wet suits, hypothermia is a major cause for concern. Exposure to cold also results in the constriction of peripheral circulatory vessels and decreased perfusion, reducing the efficiency of nitrogen elimination.[9,10] In addition to cold, other underwater environmental factors can decrease the efficacy of IWR. Strong currents often result in excessive exertion, which may exacerbate the DCI problems. (Although exercise can increase the efficiency of decompression by increasing circulation rates and/or warming the diver, it may also enhance the formation and growth of bubbles in a near- or post-DCI situation.[10]) Depending on the geographic location, the possibility of complications resulting from certain kinds of marine life (such as jellyfish or sharks), cannot be ignored.

Published methods of IWR prescribe breathing 100% oxygen at a depth of 9 m (30 ft) for extended periods of time. Such high oxygen partial pressures can lead to convulsions from acute oxygen toxicity, which can easily result in drowning.

Another often overlooked disadvantage of immersion of a diver with neurological DCI symptoms is that detection of those symptoms by the diver may be hampered. The "weightless" nature of being underwater can make it difficult to assess the extent of impaired motor function, and direct contact of water on skin may affect the diver's ability to detect areas of numbness. Thus, an immersed diver may not be able to determine with certainty whether or not symptoms have disappeared, are improving, are remaining constant, or are getting worse.

The factors described above are all very serious, very real concerns about the practice of IWR. There are really only two main theoretical advantages to IWR. First and foremost, it allows for *immediate* recompression (reduction in size) of endogenous bubbles, when transport to recompression chamber facilities will take long or when such facilities are simply unavailable. Bubbles formed as a ¡result of DCI continue to grow for hours after their initial formation, and the risk of permanent damage to tissues increases both with bubble size and the duration of bubble-induced tissue hypoxia. Furthermore, Kunkle and Beckman illustrate that the time required for bubble resolution at a given overpressure increases logarithmically with the size of the bubble.[11] Farm and colleagues suggest that "Immediate recompression within less than *5 minutes* (*i.e.* when the bubbles are less than 100 micrometers in diameter) is...essential if rapid bubble dissolution is to be achieved" (italics added).[6] If bubble size can be immediately reduced through recompression, blood circulation may be restored and permanent tissue damage may be avoided, and the time required for bubble dissolution is substantially shortened. Kunkle and Beckman,[11] in discussing the treatment of central nervous system (CNS) DCI, write:

"Because irreversible injury to nerve tissue can occur within 10 minutes of the initial hypoxic insult, the necessity for immediate and aggressive treatment is obvious. Unfortunately, the time required to transport a victim to a recompression facility may be from 1 to 10 hours.[12] The possibility of administering immediate recompression therapy at the accident site by returning the victim to the water must therefore be seriously considered."

The second advantage applies only when 100% oxygen is breathed during IWR. The increased ambient pressure allows the victim to inspire elevated partial pressures of oxygen (above those which can be achieved at the surface). This has the therapeutic effect of saturating the blood and tissues with dissolved oxygen and enhancing oxygenation of hypoxic tissues around areas of restricted blood flow.

There is also some evidence that immersion in and of itself might enhance the rate at which nitrogen is eliminated;[13] however, these effects are likely more than offset by the reduced elimination resulting from cold during most IWR attempts.

IWR in practice

Three different methods of IWR have been published. Edmonds, Lowry and Pennefather in their first edition of *Diving and Subaquatic Medicine*,[14] outlined a method of IWR using surface-supplied oxygen delivered via a full face mask to the diver at a depth of 9 m (30 ft). According to this method, the prescribed time a treated diver spends at 9 m varies from 30-90 minutes, depending on the severity of the symptoms, and the ascent rate is set at a steady 1 m every 12 minutes (approximately 1 ft/4 minutes). This method of IWR was expanded and elaborated upon in the 2nd Edition (1981),[15] and again in the 3rd Edition (1991);[4] and has come to be known as the "Australian Method". It has also been outlined in other publications[2,5,16-18] and is presented in Appendix A.

The US Navy (USN) Diving Manual briefly outlines a method of IWR to be used in an emergency situation when 100% oxygen rebreathers are available.[19] Gilliam proposed that this method could "easily be adapted to full facemask diving systems or surface supplied oxygen".[18] It involves breathing 100% oxygen at a depth of 9 m (30 ft) for 60 minutes in so-called "Type I" (pain only) cases or 90 minutes in "Type II" (neurological symptoms) cases, followed by an additional 60 minutes of oxygen at 6 m (20 ft) and 3 m (10 ft). This method is outlined in Gilliam,[18] and in Appendix B.

The third method, described in Farm et al., is a modification of the Australian Method which incorporates a 10-minute descent while breathing air to a depth 9 m (30 ft) greater than the depth at which symptoms disappear, but not to exceed a maximum depth of 50 m (165 ft).[6] Following this brief “air-spike”, the diver then ascends at a decreasing rate of ascent back to 9 m (30 ft), where 100% oxygen is breathed for a minimum of 1 hour and thereafter until either symptoms disappear, emergency transport arrives, or the oxygen supply is exhausted. This method of IWR, developed in response to the experiences of diving fishermen in Hawaii, has come to be known as the “Hawaiian Method”. This method is described in Appendix C.

All three of these methods share the requirement of large quantities of oxygen delivered to the diver via a full face mask at 9 m (30 ft) for extended periods, a tender diver present to monitor the condition of the treated diver and a heavily weighted drop-line to serve as a reference for depth. Also, some form of communication (either electronic or pencil and slate) must be maintained between the treated diver, the tending diver and the surface support crew.

Information on at least 535 cases of attempted IWR has been reported in publications. Summary data from the majority of these attempts are included in Farm et al.,[6] who present the results of their survey of diving fishermen in Hawaii. Of the 527 cases of attempted IWR reported during the survey, 462 (87.7%) involved complete resolution of symptoms. In 51 cases (9.7%), the diver had improved to the point where residual symptoms were mild enough that no further treatment was sought and symptoms disappeared entirely within a day or two. In only 14 cases (2.6%) did symptoms persist enough after IWR that the diver sought treatment at a recompression facility. None of the divers reported that their symptoms had worsened after IWR. It is also interesting (and somewhat disturbing) to note that none of the divers included in this survey were aware of published methods of IWR (i.e. all were “winging it”, inventing the procedure for themselves as they went along) and all had used only air as a breathing gas.

Edmonds et al. documented two cases of successful IWR in which divers suffering from DCI in remote locations followed the Australian Method of IWR with apparently tremendous success (Cases 8 and 9).[15] Overlock described six cases of DCI involving divers using decompression computers.[20] Of these, four attempted IWR, three with apparent success while the result in the fourth case is unclear. Two of these cases are described as Cases 1 and 5. Hayashi[7] reported two cases of attempted IWR, one of which involved the use of 100% oxygen, and the other, involving air as a breathing gas, was also described in Farm et al.[6] (1986) and is described below as Case 2.

We are aware of 20 additional cases of attempted IWR which have not previously been reported. Of these, two resulted in the death of the attempting divers who were together at the time (Cases 3 and 4) and one resulted in a sore shoulder turning into permanent quadriplegia (Case 11). Another case, for which we do not have details, involved a diver who apparently worsened his condition with IWR, but eventually recovered after proper treatment in a recompression chamber facility. In 6 other cases, the condition of the diver remained constant or improved after attempted IWR and further treatment in a recompression chamber was sought by them. In all 11 remaining cases, the diver was asymptomatic after IWR, sought no further treatment and symptoms did not return.

Without doubt, many more attempts at IWR have occurred but have not been reported. Edmonds et al. (p 175) in discussing the practice of the Australian Method of IWR, note that “Because of the nature of this treatment being applied in remote localities, many cases are not well documented. Twenty five cases were well supervised before this technique increased suddenly in popularity, perhaps due to the success it had achieved, and perhaps due the marketing of the [proper] equipment...”[15] Several professional divers have privately confided to one of us (RLP) that they have used IWR to treat themselves and companions on multiple occasions and all have reported great success in their efforts. Some continue to teach the practice to their more advanced students (although the practice was once taught on a more regular basis, it has since fallen out of widely accepted instruction protocols).

Evaluation of Case Histories

In determining the relative value of IWR as a response to DCI, it is perhaps most useful to carefully examine case histories involving attempted IWR. DCI is, by nature, a very complex, dynamic and unpredictable disorder, and evaluation of the role of IWR as a treatment in reported cases is often difficult. Assessing the success or failure of an attempt at IWR is obscured by the fact that a positive or negative change in the victim’s condition may have little or nothing to do with the IWR treatment itself. Furthermore, even the determination of whether or not a DCI victim’s condition was better or worse after attempted IWR is not always clear. For example, consider the following case, first reported by Overlock:[20]

Case 1. Fiji.

Five minutes after surfacing from the fourth dive to moderate depth (22.5-36 m or 75-120 ft) over a 24 hr period, a diver developed progressive arm and back weakness and pain. She returned to 18 m (60 ft) for 3 minutes, then ascended (decompressed) over a 50-minute period, with stops at 9 m (30 ft), 6 m (20 ft), and 3 m (10 ft), breathing air. Tingling and pain resolved during the first 10 minutes of IWR. Three hours after completing IWR, she developed numbness in the right leg and foot, and reported “shocks” running down both legs, whereupon she was taken to a recompression chamber. After 3 US Navy (USN) Table 6 treatments, she still had weakness and some decreased sensation.

The effect of IWR on the recovery of this diver is unclear. Although the pain and weakness were resolved during IWR, more serious symptoms developed hours afterward. Perhaps numbness would never have developed had the diver been taken directly to a recompression chamber instead of re-entering the water, in which case she may have responded to treatment without residuals. On the other hand, had she not returned to the water, the initial symptoms may have progressed into paralysis during her evacuation to the chamber, and she might have ultimately suffered far more serious and debilitating residuals. Cases such as this do not contribute much insight into the efficacy of IWR.

Other cases, however, provide stronger evidence suggesting that IWR has been of benefit. Consider the following case documented in Farm et al. and Hayashi:[6,7]

Case 2. Hawaii.

"Four fisherman divers were working in pairs at a site about 165 to 180 feet (49.5-54 m) deep. Each pair alternated diving and made two dives at the site. Both divers of the second pair rapidly developed signs and symptoms of severe CNS decompression sickness upon surfacing from their second dive. The boat pilot and the other diver decided to take both victims to the US Navy recompression chamber and headed for the dock some 30 minutes away (the recompression chamber was an additional hour away from the dock). During transport, one victim refused to go and elected to undergo in-water recompression, breathing air. He took two full scuba tanks, told the boat driver to come back and pick him up after transporting the other bends victim to the chamber, and rolled over the side of the boat down to a depth of 30 to 40 feet (9-12 m). The boat crew returned after 2 hours to pick him up. He was asymptomatic and apparently cured of the disease. The other diver died of severe decompression sickness in the Med-Evac helicopter en route to the recompression chamber."[7]

This is just one example of many which provide compelling evidence that IWR can, in some circumstances, result in dramatic relief of serious DCI symptoms. Ironically, had this incident occurred in an area where a recompression chamber was not an option, both divers would probably have opted for IWR, and the less fortunate victim might possibly have survived the ordeal.

On the other hand, attempts at IWR under inappropriate circumstances can lead to tragedy, as is clearly evident from the following cases:

Cases 3 and 4. Sussex, England.

Twelve experienced divers conducted an 18-minute dive on a wreck in about 64.5 m (215 ft). They surfaced after 38 minutes of air decompression, at which time two of the divers reported "incomplete decompression". These two divers obtained additional supplies of air and returned to the water in an apparent effort to treat DCI symptoms. They never returned to the boat and their bodies were recovered two weeks later.

The reason for their deaths remains a mystery. It is possible that they were suffering from neurological DCI symptoms, and drowned as a result of these symptoms. The tragedy of this case lies in the fact that they most likely would have survived had they not re-entered the water. The boat was equipped with 100% oxygen (surface-breathing) equipment and emergency air-transport could have delivered the divers to a recompression chamber less than an hour after surfacing. The water temperature in this case was about 16-17° C , and the surface conditions were relatively rough, 1-1.5 m (3-5 ft) seas. Whether or not these divers perished as a direct result of DCI symptoms, they would, in all likelihood, have survived the incident had they not returned to the water.

The main potential benefit of IWR lies in the ability to recompress the DCI victim *immediately* after the onset of DCI symptoms, before intravascular bubbles have a chance to grow or cause serious permanent damage. The apparent success of many reported attempts of IWR may be attributed to the immediacy of the recompression. In one case, reported by Overlock, IWR began before the diver even reached the surface:[20]

Case 5. Hawaii.

After ascending from his second 10-minute dive to 57 m (190 ft), a diver followed the decompression ceilings suggested by his dive computer. As he was nearing the end of his computer's suggested decompression schedule, he suddenly noticed weakness and inco-ordination in both arms, and numbness in his right leg. He immediately descended to 24 m (80 ft) where, after 3 minutes, the symptoms disappeared. After 8 minutes at 24 m (80 ft), he slowly ascended (his companion supplied him with fresh air tanks) over a period of 50 minutes to 4.5 m (15 ft). He remained at this depth until his decompression computer had "cleared". He felt tired after surfacing, but was otherwise asymptomatic.

In many other cases, IWR was commenced within a few minutes after surfacing, usually resulting in the elimination or substantial reduction of symptoms. In cases where DCI results from gross omission of required decompression, divers may anticipate the probable consequences, and often return immediately to depth as soon as possible in an effort to complete the required decompression. Two such cases are presented here:

Case 6. Hawaii.

While conducting a solo dive at a depth of 58.5 m (195 ft), a diver became entangled in lines and mesh bags. In his struggles to free himself, he extended his time at depth well beyond the intended 10 minutes and squandered much of the air he had expected to use for decompression. Upon freeing himself, he immediately began his ascent, but was mortified to discover that the boat anchor had broken loose and was gone. Swimming down-current, he fortuitously saw the anchor dragging across the bottom, and quickly caught up with the anchor line at a depth of 18 m (60 ft). At this time, his decompression computer indicated a ceiling of 21 m (70 ft), and his pressure gauge showed that his scuba tank was nearly empty. He slowly ascended to the surface and quickly explained his predicament to his companion in the boat. While waiting for his companion to rig a regulator to a fresh tank of air, he began feeling symptoms of severe dizziness and had problems with his vision. Grasping the second tank under his arm, he allowed himself to sink back down, nearly losing consciousness. Upon reaching a depth of 24 m (80 ft), his clouded consciousness fully resolved and he remained 3-4.5 m (10-15 ft) below his computer's recommended ceiling during subsequent decompression. Although he eventually left the water before his computer had "cleared", he did not experience any further symptoms.

Case 7. Central Pacific.

A diver had partially completed his decompression following 15 minutes at 60 m (200 ft), when he became aware of the presence of a very large and somewhat inquisitive Tiger Shark. Initially, the diver maintained his composure, fearing DCI more than the threat of attack. When the shark rose above, passing between the diver and the boat, the diver reconsidered the situation and opted to abort decompression. After a rapid ascent from about 12 m (40 ft), the diver hauled himself over the bow of the 17-foot Boston Whaler (without removing his gear). Anticipating the onset of DCI, he instructed his startled companion to quickly haul up the anchor and drive the boat rapidly towards shallower water. By the time they re-anchored, the diver was experiencing increasing pain in his left shoulder. He re-entered the water and completed his decompression, emerging asymptomatic.

There are many other cases in which divers must interrupt their decompression temporarily, then resume decompression within a few minutes without ever experiencing symptoms of DCI. Sur-D or surface decompression, including the use of oxygen, in a chamber is standard practice commercial (oil rig) diving. Generally, these cases of asymptomatic interrupted decompression are not considered as IWR. However, one such incident which recently occurred in Australia is worth mentioning:

Case 8. Australia.

After spending 18 minutes at a depth of 66 m (220 ft), a diver experienced a serious malfunction of her buoyancy compensator (BC) inflator which resulted in the rapid loss of her air supply and a sudden increase in her buoyancy. Additionally, she became momentarily entangled in a guide line, further delaying ascent, and was freed from the line with the assistance of her diving companion. As they ascended, they were met by a second team of divers just beginning their descent. Although one of the members of the second team was able to provide her with air to breathe, he was unable to deflate her over-expanded BC and both ascended rapidly to the surface. Within 4 minutes, she returned to a depth of 6 m (20 ft) where she breathed 100% oxygen for 30 minutes. She then ascended to 3 m (10 ft) where she completed an additional 30 minutes of breathing oxygen. Upon surfacing, she was taken to a nearby recompression chamber facility, breathing oxygen during the 30 minutes required for transport. Arriving at the facility, she noticed no obvious symptoms of DCI, but was diagnosed with mild "Type II" DCI and treated several times in the chamber. She suffered no apparent residual effects.

Although no DCI symptoms developed prior to recompression, serious symptoms undoubtedly would have ensued had recompression not been immediate, given the extent of the exposure and the explosive rate of ascent. It is interesting that a modified version of the Australian Method of IWR was employed, rather than the diver descending to greater depth on air to complete the omitted decompression. Recompression depth was limited to a maximum of 6 m (20 ft) due to concerns of oxygen toxicity at greater depths. The victim was monitored continuously while breathing oxygen underwater by at least two tending divers.

It should be noted that successful attempts at IWR are not limited to cases which take advantage of the ability to immediately recompress the victim. Edmonds et al. reported a case where IWR yielded favourable results many hours after the initial onset of DCI:[15]

Case 9. Northern Australia.

After a second dive to 30 m (100 ft), a diver omitted decompression due to the presence of an intimidating Tiger Shark. Within minutes of surfacing, he "developed paraesthesia, back pain, progressively increasing incoordination, and paresis of the lower limbs". After two unsuccessful attempts at air IWR, arrangements were made to transport the victim to a hospital 160 km (100 miles) away. He arrived at the hospital 36 hours after the onset of symptoms and, due to adverse weather conditions, he could not be transported to the nearest recompression chamber, 3,200 km (2,000 miles) away, for an additional 12 hours. By this time, the victim was "unable to walk, having evidence of both cerebral and spinal involvement", manifested by many severe neurological ailments. The diver was returned to the water to a depth of 8 m (27 ft), where he breathed 100% oxygen for 2 hours, then decompressed at 1 m every 12 minutes (the Australian

Method). Except for small areas of hypaesthesia on both legs, all other symptoms had remitted by the end of the IWR treatment.

This case suggests that in-water oxygen treatment in depths as little as 8 m (27 ft) can have positive effects on DCI symptoms even after much time has elapsed. It also underscores another aspect of IWR; the fact that it may be the *only* treatment available in remote areas where recompression chamber facilities are many thousands of kilometres and several days away. For example, Edmonds et al. report on another case which occurred in the Solomon Islands.[15] At the time, the nearest recompression chamber was 3,500 km (2,200 miles) away and prompt air transport was unavailable:

Case 10. Solomon Islands.

Fifteen minutes after a 20 minute dive to 36 m (120 ft), and 8 minutes of decompression, a diver developed severe neurological DCI symptoms, including "respiratory distress, then numbness and paraesthesia, very severe headaches, involuntary extensor spasms, clouding of consciousness, muscular pains and weakness, pains in both knees and abdominal cramps". No significant improvement occurred after 3 hours of surface-breathing oxygen. She was returned to the water and given the Australian Method of IWR, breathing 100% oxygen at 9 msw (30 ft). Her condition was much improved after the first 15 minutes, and after an hour she was asymptomatic, with no recurrence of symptoms.

Although most of the reported attempts at IWR have utilised only air as a breathing gas, this practice has been strongly discouraged due to the risks of additional nitrogen loading. The concern that air-only IWR may transform an already bad situation into tragedy seems clearly validated by the following case:

Case 11. Caribbean.

A young diver experienced pain-only symptoms of DCI after an unknown dive profile. He made three successive attempts at IWR (presumably breathing air), each time worsening his condition. After the third attempt, his condition had degenerated into quadriplegia. Because of transport delays, he did not arrive at a recompression chamber until about three days after the incident. Saturation treatment yielded no improvement in his condition, and he remained permanently paralysed.

Whereas the above case illustrates an unsuccessful attempt to treat relatively mild symptoms of DCI with air-only IWR, the following case, reported by Farm et al.,[6] represents an apparently successful attempt at treating very severe symptoms with similar techniques:

Case 12. Hawaii.

Shortly after a third dive to 66-78 m (120-160 ft), a diver developed "uncontrollable movements of the muscles of his legs". Within a few minutes, his condition deteriorated to the point where he was paralysed; numb from the nipple-line down and unable to move his lower extremities. He was able to hold a regulator in his mouth, so a full scuba tank was strapped to his back and he was rolled into the water to a waiting tender diver. The tender verified that the victim was able to breathe, and proceeded to drag him down to 10.5-12 m (35-40 ft). When the symptoms did not regress, the victim was pulled deeper by the tender. At 15 m (50 ft), he regained control of his legs and indicated that he was feeling much better. He was later supplied with an additional scuba tank, ascended to 7.5 m (25 ft) for a period of time and then finished his second tank at 4.5 m (15 ft). Except for feeling "a little tired" that evening, he regained full strength in his arms and legs and remained asymptomatic.

Another, previously unpublished case, involved a DCI victim whose symptoms were so severe that IWR was not attempted for fear that he would drown:

Case 13. Central Pacific.

Four aquarium fish collectors ascended rapidly from their second 60 m (200 ft) dive of the day, aborting essentially all decompression. All immediately began experiencing nausea and varying degrees of neurological DCI symptoms. Three of the divers returned to a depth of about 15 m (50 ft), but the fourth opted instead to stay in the boat. When the three completed their abridged attempt at IWR (after which all three felt noticeably improved), they headed for shore. Help was summoned, and additional scuba tanks and 100% oxygen were obtained and loaded into the boat. By this time, one of the divers felt only pain in his shoulders, and the other three were experiencing varying degrees of neurological DCI symptoms. The worst of these was diver who did not attempt IWR immediately after the initial onset of symptoms. He was unable to move his arms or legs and was having difficulty breathing. The other three attempted to assist him back in the water, but they eventually gave up, fearing that he might drown (due to his inability to hold the regulator in his mouth). The other three continued IWR, breathing both air and 100% oxygen at 9-12 m (30-40 ft), until nightfall forced them out of the water. That night, all four took turns breathing 100% oxygen on the surface while waiting for the emergency evacuation plane to arrive. The following day, the three who had attempted IWR were flown to Honolulu, where they experienced varying degrees of recovery after treatment in a recompression chamber. The one who did not attempt IWR died before the plane arrived.

All of the cases described thus far have involved either 100% oxygen or air (or both) as breathing gasses during IWR. In at least one reported case, Enriched Air Nitrox (EAN) was used as a breathing gas for the IWR treatment:

Case 14. North eastern United States.

After spending 25 minutes at a maximum depth of 44.5 m (147 ft), a diver ascended using the decompression stops required by his tables. He began feeling a tingling sensation and sharp pain in his right elbow as he arrived at his 9 m (30 ft) decompression stop. He completed an additional 30 minutes at 3 m (10 ft) beyond what was called-for by his tables, and then surfaced. His symptoms subsided somewhat after an hour of breathing 100% oxygen on the boat, but persisted enough to prompt the diver to attempt IWR. He returned to the water with an additional cylinder containing EAN-50 (50% oxygen, 50% nitrogen) and descended to 30 m (100 ft) for a period of 10 minutes. He ascended to 6 m (20 ft) over a 10-minute period and remained there for 68 minutes. He spent an additional 5 minutes at 3 m (10 ft), then surfaced asymptomatic, with no recurrence of symptoms.

This case illustrates another fundamental risk associated with IWR; that of acute CNS oxygen toxicity. During the deepest portion of above IWR profile, the diver was breathing an oxygen partial pressure of 2.02 bar, considerably greater than is considered safe. The diver was aware of the potential for acute CNS oxygen toxicity and had an additional cylinder of air with him, just in case. However, he was exposed to this excessive oxygen partial pressure for only 10 minutes.

Should IWR be used?

The source of controversy surrounding the topic of in-water recompression is essentially the conflict between what is predicted by theory and what appears to be demonstrated by practice. In reviewing the issue of IWR, several questions require attention. First and foremost, should IWR ever be attempted under any circumstances? If the answer is “yes”, then under what circumstances should it be performed? Also, if the decision to perform IWR has been made, which method should be followed?

The efficacy of IWR

From the cases described above, it should be evident that IWR has almost certainly been of benefit to some DCI victims in certain circumstances. If the selection of cases seems biased towards “successful” attempts at IWR, it is only a reflection of the numbers of actual cases on record (Table 1). Whereas only one additional attempt at IWR (besides Cases 3, 4 and 10) clearly led to deterioration of the condition of a DCI victim, there are literally *hundreds* of additional cases where IWR was almost certainly of (sometimes great) benefit.

TABLE 1

527 IN-WATER RECOMPRESSIONS IN HAWAII

Complete resolution of symptoms	462
Residual symptoms but no further treatment sought as symptoms disappeared within a few days	51
Residual symptoms needing further treatment	14
Divers made worse by in-water recompression	0
Total	**527**

Compiled from Farm.[6]

Opponents to the practice of IWR are usually quick to point out that DCI symptoms are often relieved, sometimes substantially, when the victim breathes 100% oxygen at the surface (the presently accepted and recommended response to DCI). Indeed, if symptoms do resolve with surface-oxygen, and recompression treatment facilities are relatively close at hand, then the additional risks incurred with re-immersion seems unwarranted. The two deceased divers discussed in Cases 3 and 4 would have, in all likelihood, survived their ordeal if oxygen had been administered on the boat and transport to the nearby recompression chamber arranged. However, in cases where chamber facilities are not available, or when symptoms persist in spite of surface-oxygen (such as in Cases 10 and 14), then recompression is clearly necessary, and IWR perhaps should be attempted.

Determining circumstances appropriate for IWR

It should also be clear that identifying those circumstances under which IWR should be implemented is an exceedingly difficult task. A wide variety of variables must be taken into account, and many factors must be carefully considered. Although the decision to perform IWR should be made quickly, it should *not be made in haste*.

Hunt pointed out that DCI often carries with it a certain stigma.[21] Under some circumstances, a diver suffering from the onset of DCI symptoms may be reluctant to reveal their condition to companions. Consequently, such an individual might attempt IWR so as to “fix” themselves without anyone else becoming aware of the problem. For obvious reasons, this alone is *not* a reasonable justification for considering IWR and is especially dangerous because it likely results in the diver attempting IWR without the safety of an observing attendant or tender. Similarly, IWR should never be thought of as a substitute for proper treatment in a recompression chamber. IWR is not a “poor man’s treatment”, and the decision to implement it should not be motivated by financial concerns. Regardless of the outcome of an IWR attempt, medical evaluation by a trained hyperbaric specialist should always be sought as soon afterward as possible.

The major factor in determining whether IWR should be implemented is the distance and time to the nearest recompression facility. In 1963, Rivera studied more than 900 cases of DCI in USN divers, found that 91.4% of the cases treated within fifteen minutes were successful, whereas the success rate when treatment was delayed 12-24 hours was 85.7%.[22] A similar study on DCI cases among sport (recreational) divers showed similar results. Of 394 examined cases, 56% of divers with mild DCI symptoms achieved complete relief when treated within 6 hours, whereas only 30% were completely relieved when treatment was delayed 24 hours or more.[23] The same study found that 39% of divers with severe symptoms were relieved when treated within 6 hours, whereas only 26% were relieved when treatment was delayed 24 hours or more. In reviewing these numbers, Moon stressed that delay of treatment for DCI should be minimised, but also noted that response to delayed treatment is not entirely unacceptable.[24] Knight recommends that IWR should be considered when the nearest recompression facility is more than 6 hours away.[17] Such generalisations are difficult to make, however, as indicated by the fact that the ill-fated diver in Case 2 was less than 2 hours away from a recompression chamber.

One of the most important variables affecting the decision to attempt IWR is the mental and physical state of the diver. Certainly divers who are, for whatever reason, uncomfortable or reluctant to return to the water for IWR should not be coerced or forced to do so. The extent and severity of the DCI symptoms are also important factors. Whether or not mild DCI symptoms (i.e. pain-only) should be treated is not certain. One perspective is that such symptoms are not likely to leave the diver permanently disabled, and thus the risks associated with attempted IWR would not be worth taking. Furthermore, individuals with such symptoms are prime candidates for “making a bad situation worse” (as was demonstrated in Case 11). Conversely, the risks of submerging severely incapacitated divers might override the potential benefits of IWR when serious neurological manifestations are evident. Edmonds recommends against the practice of IWR in situations “where the patient has either epileptic convulsions or clouding of consciousness.”[5] The death of the two divers in Cases 3 and 4 might have resulted from drowning due to loss of consciousness from severe neurological symptoms. However, some evidence indicates that IWR may be of value even under these circumstances. Although the divers treated in some cases (e.g. Cases 2, 6, and 12) might have gone unconscious underwater and drowned, the consequences of no immediate recompression may have been equally grave. Also, the diver who perished in Case 13 may have survived had he performed IWR along with his companions.

The immediacy of recompression may be particularly advantageous if DCI symptoms develop soon after surfacing from a deep dive, and when these symptoms are neurological and progressive.[25] Under such circumstances, the condition of the DCI victim can rapidly degenerate and permanent damage may ensue in the absence of immediate recompression. However, it is also particularly critical in these circumstances to monitor the condition of the treated diver with a tender close by.

As mentioned earlier, environmental factors such as water temperature, surface conditions, hazardous marine life, and strong currents might significantly influence the feasibility of IWR. Many technical dives are conducted in relatively cold water (such as Europe, the north eastern and western coasts of the continental United States, southern Australia, and many freshwater systems) and the risk of hypothermia and decreased nitrogen elimination rates create additional complications for attempted IWR in these environments. Edmonds et al. and Edmonds have pointed out that reduced water temperature is not necessarily as great a concern as many opponents of IWR have suggested.[5,15] The reasoning is that divers in these environments are usually well-equipped with thermal protection such as dry-suits, which have come into wide-spread use among technical divers. If the divers have adequate thermal protection to conduct the initial dive, then they are likely prepared to tolerate additional in-water exposure during IWR. However, Sullivan and Vrana reported after two cases of simulated IWR off Antarctica in -1.4° C water that IWR “cannot be considered sufficiently reliable in [extremely] cold waters...”[26]

Sharks and other hazardous marine life can complicate IWR efforts. In Case 6, a large Tiger Shark did appear during IWR, but did not influence the diver’s ascent profile. Divers omitted required decompression in Cases 7 and 9 due to the presence of large Tiger Sharks, which led to subsequent attempts at IWR. The risks of this threat are generally minuscule, however these cases illustrate that such problems can occur.

In addition to the factors discussed above, the availability of large quantities of 100% oxygen and the equipment needed to deliver it safely to a diver 9 m (30 ft) underwater are also very important factors when considering an attempt at IWR. These factors are discussed in greater detail in the following section.

Methodology of IWR

Once the decision to perform IWR has been made, the next question to consider concerns methodology. The fundamental difference between the Australian Method and the Hawaiian Method of IWR is that the latter incorporates a deeper “air-spike” as an initial step in the treatment. The two methods are analogous in form, respectively, to the USN

Table 6 and Table 6A. However, the depths at which 100% oxygen is breathed are shallower, and the durations shorter for the IWR methods than for the chamber schedules.

The primary purpose for the deeper "air-spike" of the Hawaiian Method is essentially to exert a greater pressure on the diver so that the DCI bubbles are further reduced in size. In addition to restoring circulation, the extra "overpressure" may facilitate bubble resolution.[6,11] Air is used instead of oxygen because of the risk of acute CNS oxygen toxicity which results from breathing oxygen at such depths. Along with the benefits of increased bubble compression, however, come the risks of additional nitrogen absorption during this "spike".

To address the therapeutic advantages of the "spike", it is important to examine the physical effects of pressure on bubble size. Although by Boyle's Law there is a substantial diminishing of returns in terms of bubble size reduction as one descends deeper, gas bubbles are subject to other forces that may affect their size. Although a discussion of bubble physics is beyond the scope of this article, suffice it to say that bubble radii are reduced proportionally more with increasing depth than would be predicted by Boyle's Law alone. Perhaps more importantly, the pressure of the gas within the bubble increases proportionally more, which leads to increased rates of bubble dissolution. However, the risks of nitrogen loading and nitrogen narcosis increase with depth, adding potentially substantial greater risk to performing the deep spike. A depth of 50 m (165 ft) was chosen by the USN Table 6A and the Hawaiian Method as the maximum at which benefit from recompression was significant.[6] Descent to a depth of 9 m (30 ft), the maximum depth prescribed by the Australian Method, yields a nearly 50% reduction in bubble volume and approximately 20% decrease in bubble diameter. Descent to 50 m (165 ft) further reduces the bubble volume by an additional 33%, and the diameter by an additional 25%. Thus, in the case of bubble volume, more benefit results in the first 9 m (30 ft) of recompression than is gained in the next 41 m (135 ft), whereas the reduction in bubble diameter is slightly greater during the subsequent 41 m (135 ft) depth than the initial 9 m (30 ft). Whether or not bubble diameter or bubble volume is more critical to the manifestation of DCI symptoms is uncertain.

The fundamental question is whether or not the additional recompression confers physiological advantages sufficiently in excess of the disadvantages associated with breathing air at depth (in an IWR situation). Obviously, this depends on the immediate diving history of the afflicted diver and the particular circumstances involved. The practice of subjecting DCI victims to a 50 m (165 ft) spike during chamber treatments has recently begun to fall out of favour among hyperbaric medical specialists. Hamilton points out that "the 6-atm recompression with air or enriched air of Table 6A is likely to be discontinued as evidence accumulates that it offers no real benefit over the 100% oxygen [treatment] of Table 6".[27] This philosophy may also be applied to IWR treatment procedures. The possibility of substituting Enriched Air Nitrox (EAN) or high-oxygen Heliox during the "spike" must also be examined. Modern technical diving operations often involve EAN for some portion of the dive and thus EAN may be available in some DCI situations. EAN contains a percentage of oxygen which is greater than 21% and may offer therapeutic advantages over air. The presence of nitrogen as a diluent in EAN allows a diver attempting IWR to recompress at a greater depth than permitted by CNS oxygen toxicity when using 100% oxygen. In at least one case (Case 14), EAN was used during IWR, with apparently successful results. James outlined the benefits associated with using 50/50 Heliox (50% helium, 50% oxygen) for recompression therapy.[28] Since helium mixtures commonly incorporated into technical diving operations do not contain such high proportions of oxygen, a supply of high-oxygen Heliox would have to be maintained at the dive site specifically for the purpose of IWR. Unless closed-circuit rebreathers are available at the site, the option of using Heliox for IWR is probably not feasible.

There are a number of safety advantages to the Australian Method over the Hawaiian Method. Since the only breathing gas of the Australian Method is oxygen, there is no risk of additional loading of nitrogen or other inert gases. Thus, if the treatment must be terminated prematurely (e.g. in response to the onset of nightfall; see Case 13), there is no risk of aggravating the DCI symptoms. Furthermore, the Australian Method may be conducted in shallow, protected areas such as lagoons or boat harbours, where sea surface and current conditions are less likely to be adverse.

We are unable at this time to entirely condemn the Hawaiian Method of IWR, for it may confer important advantages under certain circumstances. Edmonds suggests that the Australian Method of IWR is "of very little value in the cases where gross decompression staging has been omitted", presumably because such situations may require recompression to depths in excess of 9 m (30 ft) (although see Cases 8 and 9).[5] Under such circumstances, interrupted decompression situations, the "spike" might be advantageous. Nevertheless, we are compelled to strongly discourage technical divers from incorporating an "air-spike" into IWR attempts, at least until additional verification of its efficacy can be established through empirical and theoretical lines of evidence.

The USN method of IWR differs from the Australian Method primarily in the recommended ascent pattern. Whereas the Australian Method advocates a slow steady (1 m/12 minutes.) ascent rate, the USN Method divides the ascent into two discrete stages directly to 20 and again to 10 ft. Although at first this difference may seem trivial, it might, in fact, have important physiological ramifications. Edmonds reports that "It is a common observation that improvement continues throughout the ascent, at 12 minutes per metre. Presumably the resolution of the bubble is more rapid at this ascent rate than its expansion, due to Boyle's Law".[5] If this is true, then divers attempting IWR according to the USN Method could conceivably suffer recurrence of symptoms immediately following ascent to the next shallower stage. The validity of this argument has yet to be verified.

Hyperbaric Oxygen

All of the published IWR methods advocate breathing an oxygen partial pressure of 1.9 bar for extended periods. Such high levels permit increased saturation of dissolved oxygen in the blood and tissues, which may help provide badly needed oxygen to areas of restricted circulation or tissue hypoxia. However, at such concentrations and durations the risks of acute CNS oxygen toxicity are a serious consideration. Oxygen partial pressures of 1.2-1.6 bar have been suggested as the upper limit for technical diving operations.[29] The published IWR methods have endorsed exposure to higher oxygen partial pressures because of the therapeutic advantages and because a diver performing IWR is apt to be at rest which reduces the likelihood of an acute oxygen toxicity seizure. In at least one case (Case 8), the depth of in-water oxygen treatment was limited to a maximum of 6 m (20 ft), giving an oxygen partial pressure of 1.6 bar, in an effort to avert oxygen toxicity problems. Because the consequences of convulsions resulting from acute oxygen toxicity are particularly serious underwater, all three published methods of IWR strongly recommend that an attendant diver be continuously present and that oxygen be administered using a full face mask. Although not prescribed in any of the in-water recompression methods, most recent publications discussing the use of oxygen as a decompression gas advise that the long periods of breathing pure oxygen be "buffered" by 5-minute air breaks every 20 minutes. The risk of additional nitrogen loading from these brief periods is more than offset by the reduced risk of acute oxygen toxicity problems.

Standard recompression chamber treatments commonly incorporate breathing 100% oxygen at a pressure equivalent to a depth of 18 m (60 ft) or 2.8 bar, however this should not be attempted during IWR due to changes in human metabolism when immersed in water and to the grave consequences of an oxygen toxicity-induced convulsion underwater.

In the absence of oxygen

Perhaps one of the most critical conditions affecting the decision to perform in-water recompression is the availability of 100% oxygen, especially in a system capable of delivering it to a diver underwater. Although the risk of acute oxygen toxicity symptoms is certainly a cause for concern, the added advantages to effective decompression/recompression are tremendous. However, there will be cases of DCI which occur in situations where 100% oxygen is unavailable. Surely, in light of the theoretical disadvantages of attempting IWR using only air, such a practice would seem absurd. Indeed, all of the cases for which IWR left the divers in worse shape than when they began (e.g. cases 3 and 11), involved air as the only breathing mixture. Furthermore, the diver in case 9 did not improve after air-only IWR and may have exacerbated his condition during his failed attempts. Nevertheless, the vast majority of the reported "successful" attempts of IWR (including cases 2, 5, 6, 7 and 12) were conducted using only air. Several early publications proposed methods of air-only IWR,[30] however none are presently recognised as practical alternatives to oxygen IWR.

In two of the above cases of air-only IWR (cases 5 and 6), the afflicted divers followed the advice of their decompression computers in determining an air recompression/decompression profile, with apparent success. However, as pointed out by Overlock, use of computers for this purpose "was never intended by the designer/manufacturer, nor would it be recommended".[20] This practice is not advisable as the algorithms utilised by such devices for determining decompression profiles do not account for the complexities introduced by the presence of intravascular bubbles, which can dramatically affect decompression dynamics.[31]

Edmonds et al. sum up air IWR as follows: "In the absence of a recompression chamber, [air IWR] may be the only treatment available to prevent death or severe disability. Despite considerable criticism from authorities distant from the site, this traditional therapy is recognised by most experienced and practical divers to often be of life saving value".[15]

Our suggestion (and an underlying message of this paper), is that technical divers, who are already familiar with the use of 100% oxygen underwater as a decompression gas, should add to their equipment inventory the necessary items (such as a full face mask and large supplies of extra oxygen) to perform proper IWR procedures. Having done this, these divers avoid facing the decision to perform the risky gamble of air IWR.

Conclusions

The main purpose of this article is to bring forth the issue of IWR as an alternative response to DCI, and to summarise available information on the subject. We do not necessarily endorse IWR; however we see an increasing need for technical divers to become aware of the information available on this topic. Several disturbing facts have prompted us to bring this issue to light.

First, based on available reports, it is clear that many people are attempting IWR without even knowing that published procedures are available. Furthermore, most reported attempts were conducted using only air. Although the practice seems to have led to a surprising number of successful cases, the advantages of using oxygen for IWR are tremendous and cannot be denied. Thirdly, and perhaps of greatest concern, few of the individuals who successfully attempted IWR sought subsequent examination by a trained diving physician.

We feel compelled to emphasise strongly the importance of seeking a thorough medical examination after any situation where DCI symptoms have been detected. Regardless of how successful an attempted IWR procedure may be, the affected divers should arrange for transport to the nearest recompression facility as soon as possible to undergo examination by a trained hyperbaric medical specialist. The practice of IWR should never be viewed as an alternative to proper treatment in a recompression chamber. Rather, it should be viewed as a means to arrest and possibly eliminate a progressing or otherwise serious case of DCI. In most cases, in-water recompression should be used as an immediate measure to arrest or reverse serious symptoms while arrangements are being made to evacuate the victim to the nearest operating chamber facility. Without doubt, a person suffering from DCI is better-off within the warm, dry, controlled environment of a chamber, under proper medical supervision, than he or she is hanging on a rope underwater.

The information contained in this article is directed at the growing numbers of "technical" divers, who are conducting dives which expose them to elevated risk of sustaining serious DCI symptoms. These sorts of divers tend to be more experienced and better prepared and equipped to handle many of the procedures outlined by published IWR methods. As put forth by Menduno,[1] "In-water oxygen therapy appears to be a promising, though perhaps transitional, solution to the problem of field treatment for technical divers. Though the concept will take some work to properly implement on a widespread scale, the technical community does not suffer from the same limitations as its mass market counterpart." By "transitional", Menduno was no doubt referring to the possibility that lightweight, portable recompression chambers may soon become standard technical diving equipment, and may be available on a much broader basis in the future. Selby describes one such chamber design which can be compactly stored and quickly assembled in field emergency situations.[32] Edmonds,[5] however, cautions that:

"When hyperbaric chambers are used in remote localities, often with inadequate equipment and insufficiently trained personnel, there is an appreciable danger from both fire and explosion. There is the added difficulty in dealing with inexperienced medical personnel not ensuring an adequate face seal for the mask. These problems are not encountered in in-water treatment."

In any case, the present high cost of portable recompression chambers will prevent their widespread availability anytime soon. Furthermore, there will always be DCI incidents in situations where no recompression chambers are available nearby.

Our intention is to illustrate that the issue of IWR is far from clearly resolved. We have little doubt that staunch opponents to the practice of IWR will angrily object to even discussing the issue, on the grounds that it might lead improperly trained individuals to make a bad situation worse. But we adhere to the idea that the dissemination of information to those who may need it is of utmost importance, especially when lives may be at stake. It is indeed tragic when a person suffering a relatively minor ailment resulting from DCI attempts IWR incorrectly and leaves the water permanently paralysed or dead. However, it is perhaps equally tragic when a DCI victim ends up suffering from permanent disabilities because of a long delay in transport to a recompression facility, when the damage might have been reduced or eliminated had IWR been administered in a timely manner. We believe that the time has come to address this issue seriously, openly and with as much scrutiny as possible. Only through further controlled experimentation and careful analysis of reported IWR attempts will this controversial issue progress towards resolution.

In an effort to document larger numbers of IWR cases, we have begun to collect data on this topic and intend to establish a database of reported IWR attempts. If any readers have ever attempted IWR, or know of anyone who has, we would be greatly indebted if information could be sent to Richard L. Pyle, Ichthyology, B P Bishop Museum, PO Box 19000-A, 1525 Bernice Street, Honolulu, Hawaii 96817, USA. or sent by fax to +1-808-841-8968.

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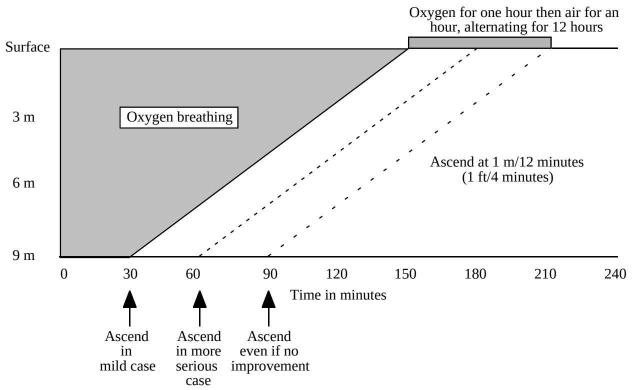
A version of this paper was originally published in aquaCorps 1995; Number 11 (UNDERGROUND XPLORERS):35-46 without references. auquaCorps has ceased publication and the paperhas been revised and references added for this reprinting.

APPENDIX A

THE AUSTRALIAN METHOD OF EMERGENCY IN-WATER RECOMPRESSION



Notes

1 This technique may be useful in treating cases of decompression sickness in localities remote from recompression facilities. It may also be of use while suitable transport to such a centre is being arranged.

2 In planning, it should be realised that the therapy may take up to 3 hours. The risks of cold, immersion and other environmental factors should be balanced against the beneficial effects. The diver must be accompanied by an attendant.

Equipment

The following equipment is essential before attempting this form of treatment.

1 Full face mask with demand valve and surface supply system or helmet with free flow.

2 Adequate supply of 100% oxygen for patient and air for attendant.

3 Wet suit (or dry suit) for thermal protection.

4 Shot line with at least 10 m of rope (a seat or harness may be rigged to the shot).

5 Some form of communication system between patient, attendant and surface.

Method

1 The patient is lowered on the shot rope to 9 m breathing 100% oxygen.

2 Ascent is commenced after 30 minutes in mild cases, or 60 minutes in severe cases, if improvement has occurred. These times may be extended to 60 minutes and 90 minutes respectively if there is no improvement.

3 Ascent is at the rate of 1 m every 12 minutes or 1 foot every 4 minutes.

4 If symptoms recur, stop ascent and remain at depth a further 30 minutes before continuing ascent.

5 If oxygen supply is exhausted, return to the surface, rather than breathe air.

6 After surfacing the patient should be given one hour on oxygen, one hour off, for a further 12 hours.

TABLE AUST 9 (RAN 82) SHORT OXYGEN TABLE

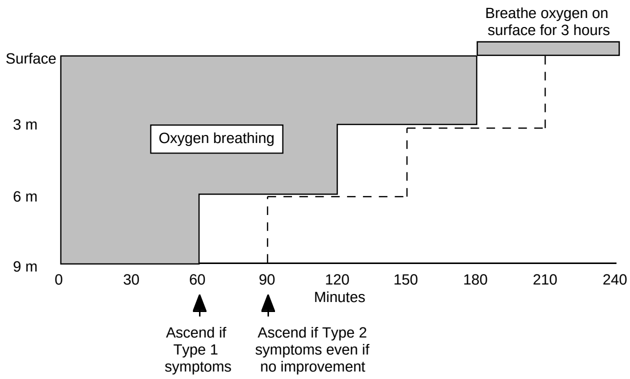
Ascent rate 12 minutes per m (4 minutes/ft)

Depth (msw)	Elapsed Time in Minutes			
	Mild cases		Serious cases	
	No symptoms	Remaining symptoms	No symptoms	Remaining symptoms
9	30	60	60	90
8	42	72	72	102
7	54	84	84	114
6	66	96	96	126
5	78	108	108	138
4	90	120	120	158
3	102	132	132	162
2	114	144	144	174
1	126	156	156	186

After Edmonds et al. p.558.[15]

APPENDIX B

THE US NAVY METHOD OF EMERGENCY IN-WATER RECOMPRESSION



"If the command has 100% oxygen-rebreathers available and individuals at the dive site trained in their use, the following in-water recompression procedure may be used instead of Table 1A:

1 Put the stricken diver on the rebreather and have him purge the apparatus at least three times with oxygen.

2 Descend to a depth of 9 m (30 ft) with a stand-by diver.

3 Remain at 9 m (30 ft), at rest, for 60 minutes for Type I symptoms and 90 minutes for Type II symptoms. Ascend to 6 m (20 ft) after 90 minutes even if symptoms are still present.

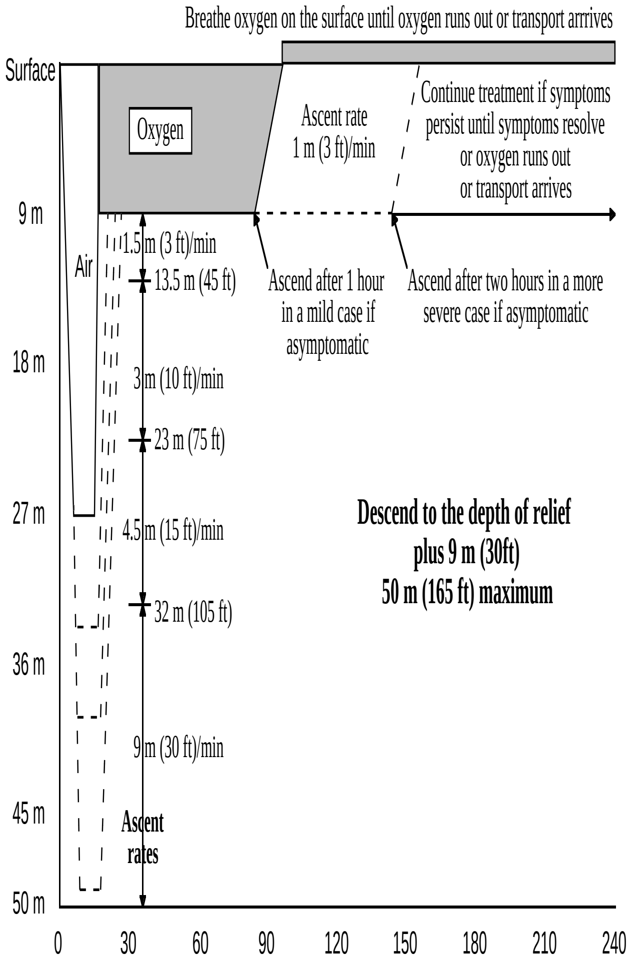
4. Decompress to the surface by taking 60 minutes stops at 6 m (20 ft) and 3 m (10 ft).

5 After surfacing, continue breathing 100% oxygen for an additional three hours."

From the U.S. Navy Diving Manual, Vol. One, Section 8.11.2, D.[19]

APPENDIX C

THE "HAWAIIAN METHOD" OF EMERGENCY IN-WATER RECOMPRESSION



Notes

This decompression sickness treatment table was designed for use by Hawaii's diving fishermen when afflicted with decompression sickness while diving and when more than 30 minutes away from a recompression treatment facility.

In such an event, treatment must be initiated as soon as the signs or symptoms of decompression sickness are recognised. The urgent nature of the treatment must be recognised and acted upon immediately, inasmuch as nervous tissue of the brain or spinal cord can only be completely revived within the first 7 to 8 minutes after its oxygen supply has been stopped by the intravascular bubble emboli of decompression sickness.

(Although its use by technical divers is generally discouraged, this method is presented here for the purpose of providing information to readers. Readers are strongly advised to obtain a copy of Farm et al. for further details concerning this treatment. Some suggested modifications to allow for more general applicability of this method and some additional comments have been added in italics.)[6]

Equipment Required

1 An adequate supply of oxygen on board the boat, i.e. a 120 cu ft capacity or greater bottle, an oxygen-clean hose at least 12 m (40 ft) long plus fittings, and an oxygen-clean scuba regulator and mouth piece (*NOTE: Use of full face mask with demand regulator is very strongly encouraged for administering oxygen underwater during these treatments*).

2 A length of line marked to 9 m (30 ft) from the waterline with seat attached upon which the victim can sit during decompression (t*he seat should be weighted so as to make victim and seat negatively buoyant*).

3 Extra air tanks for victim and attending diver (*minimum of two*).

4 Anchor rope or sounding float line marked at 50 m (165 ft).

5 Depth gauge and watch for use by attending diver.

6 Wet suit (or other adequate thermal protection) for use by victim with appropriate weights.

Method

Upon recognising symptoms or signs of decompression sickness, **immediately**

1 Stop the engines (of the boat, if the boat is already moving).

2 Throw over anchor line and let out 165 feet or to bottom.

3 Rig one full air tank for victim and another for attendant diver.

4 Put victim in water with one attendant diver (*or two if required*) to take victim down anchor line. Extreme caution should be exercised in choice of attendant diver. The risk of DCI occurring in the attendant diver as a result of the IWR attempt should be very seriously considered.

5 Descend to depth of relief plus 9 m (30 ft). Do not exceed 50 m (165 ft).

6 Keep victim at that depth for 10 minutes.

7 Attending diver and victim start slow ascent with initial rate of 9 m/ minute (30 ft/minute) with stops every minute for assessment of patient's condition.

8 Ascent from maximum depth to oxygen breathing depth should not take less than 10 minutes. Suggested rates of ascents from 50 m (165 ft) are: 9 m/ minute (30 ft/minute) x 2 minutes; 4.5 m/minutes (15 ft/minute) x 2 minutes; 3 m/ minute (10 ft/minute) x 3 minutes; 1.5 m (5 ft/minute) x 3 minutes.

9 If patient starts to experience recurrence of any signs or symptoms, return to 3 m (10 ft) deeper stop for 5 minutes, then resume ascent.

10 During deep air breathing period, crew in boat rigs

oxygen breathing equipment with regulator (*or preferably, full face-mask with demand regulator*) attached to hose and line with seat at 9 m (30 ft).

11 Upon reaching 9 m (30 ft) victim switches to oxygen breathing.

12 Victim breathes oxygen at 9 m (30 ft) for a minimum of 1 hour.

13. If victim had initial symptoms of pain only, and if signs and symptoms are relieved after 1 hour of breathing oxygen, start slow ascent. If victim had signs and symptoms of CNS disease, keep victim at 9 m (30 ft) on oxygen for one or two additional 30 minute periods. When victim is completely relieved (*or emergency transport arrives or oxygen supply is exhausted*), start slow ascent to surface while breathing oxygen (*or air if oxygen supply is exhausted*)

14 If the in-water recompression is not effective and the supply of oxygen is apparently inadequate, emergency transport to the on-shore recompression chamber should be arranged. Technical divers are strongly encouraged to begin making arrangements for emergency transport to a recompression facility as soon as DCI symptoms become evident. Recompression on oxygen at 9 m (30 ft) should be continued until the oxygen supply is exhausted or transport arrives.

15 Even if victim is asymptomatic when reaching surface, have victim breathe oxygen in the boat until the supply is exhausted. Consult with diving medical officer upon return to shore.

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TECHNICAL DIVING

Carl Edmonds

Key Words

Accidents, deep diving, mixed gas, rebreathing, safety, technical diving.

Introduction

There is considerable doubt as to whether this information should be included in a text dealing with safety aspects of scuba diving. The authors sincerely wish that no normal recreational scuba diver would get involved with this extension of "the diving envelope".

The proponents of technical diving would have you believe that there is very little risk, either as regards death or injury in normal recreation scuba diving (breathing compressed air to a maximum depth of 30-40 m). This is not true, but it can be supported by selective use (or misuse) of statistics.

The reader should know that most of the diving accidents and deaths that occur in recreational scuba diving are not due to decompression sickness. Indeed the major causes include the hazards of the ocean environment, the stress responses on the individual, equipment failure or misuse and some diving practices which are especially hazardous, such as exhaustion of the air supply, buoyancy problems and failure to follow buddy diving practices.

Nevertheless, by concentrating mainly on decompression sickness, it can be made to appear that the accident rate is small for recreational scuba divers. And so it is, if restricted to that particular illness. When divers purport to reduce the incidence of decompression sickness by various techniques, while at the same time increasing the hazards from the more common diving problems, one has to question the motivation.

In Australia, a number of experts in "technical diving" have succumbed to the problems inherent in this activity. Their deaths, usually soon after a marketing campaign to promote this activity, have probably served to protect many younger and less experienced divers.

Definition

I use technical diving to cover diving in excess of the usual range for recreational scuba divers, no-decompression, open circuit, air breathing scuba diving to 40 m. Technical diving may involve an extension of duration at any depth, the depth itself (in excess of 30-40 m), changing the gas mixtures to be used, or using different types of diving equipment. All these fall into the realm of technical diving.

Decompression and deep diving using only compressed air have added risks. Technical diving developed in an effort to avoid some of these risks.

It is important, when discussing technical diving, to specify which type, as the risk varies from little or no additional risk (compared with recreational diving) to an extremely high one, such as with re-breathing equipment. The risks increase as the gas mixture deviates from normal air and with increased complexity of the equipment.

Diving on 32% oxygen, 68% nitrogen instead of air to a maximum of 40 metres on a no-decompression conventional air profile, could possibly incur slightly less risk than a recreational scuba air dive.

The technical diver

The technical diver is, or should be, a very experienced scuba diver, having logged at least 500 dives before entering this new field. It is usually a male, oriented towards technical toys. He often has a high intelligence but an even larger ego, frequently is obsessional in his attention to detail (which may increase his chances of survival), often studious and attracted to risk taking behaviour with a reduced safety margin, even if it risks death.

He will apply considerable funds and time to his project. Often this has commercial implications, and he may well be involved in wreck salvage, equipment manufacture, marketing and sales, diver training, or other commercial ventures.

The diver attempts to select the theoretically ideal gas mixture for the ascent and descent (travel mixes), the bottom (bottom mix) and the decompression staging (usually oxygen).

Problems

Technical diving involves more complex equipment, for producing, supplying and delivering the various gases other than air. With an increase in the complexity of the equipment there is an associated increase in the likelihood of human error at all three stages.

Problems develop from:

Mixing and transport of gas;

Handling it at the dive site;

Analysing the gas and confirming that it is the one appropriate for the dive to be performed;

Selection of appropriate gases during the dive.

Different gases require different cylinders together with the various attachments; manifolds, O rings, contents gauges, high pressure hoses, and separate regulators.

The handling of mixtures with higher than normal oxygen percentages implies greater risk of fire and explosion.

When there are various gas mixtures being breathed, the safe profile of the dive may be very complex. Decompression regimes are often unproven and inadequate factual information is available regarding the physiological interactions of the gases.

There is considerable doubt regarding many of the physiological assumptions on which technical diving is performed. It is claimed that the equivalent air depth (EAD) can be used to determine the influence of the gas mixture on the diver, and this has been related to both nitrogen narcosis and decompression sickness (DCS). There is, in fact, no really good evidence that this EAD is appropriate to either.

There are also the physiological implications of breathing oxygen at varying partial pressures, as well as the often increased carbon dioxide retention with both high oxygen diving and deep diving. The use of gas mixtures is also likely to influence the transfer of inert gases in many ways, far more complex than can be sensibly deduced from a simplistic formula. Anyone who doubts this should peruse one of the more sophisticated texts on such topics as nitrogen narcosis and the counter diffusion of gases.

Financially there are increased initial capital outlays, operating and maintenance costs.

The main purpose of technical diving is to extend the environments into which diving is performed. This usually means an increase in the hazards associated with such environments. The exception is a reduction of the nitrogen narcosis of deep diving, by the use of helium. Most of the other problems with deep diving are aggravated. Not only can the depth or duration of the dive be extended, but so can the actual diving terrain. This is the reason why many wreck divers and cave divers have embraced this activity.

The result is that the mix-gas diver often wears a large amount of equipment, extremely complex and bewildering, especially when other environmental problems develop during the dive. The likelihood of equipment problems has been compounded greatly. Other related difficulties include buoyancy variations and sometimes the need for a full face mask, so that drowning is less likely and rescue becomes more possible.

Because of the different equipment and gases, and the extension of the environments, the techniques for accident management and rescue have to be altered to take into account the specific problems. With each variation from the conventional scuba system, there is a price to pay, and a modification of the first aid and treatment procedures.

Oxygen Pressure

There is little concern about oxygen toxicity with recreational compressed air diving in the no-decompression range. Neurological and respiratory oxygen toxicity are virtually impossible. Also, the amount of oxygen taken in is unlikely to significantly influence any recompression treatments that may be needed for decompression accidents. Neither statement can be applied to technical diving.

It had been assumed that oxygen, by virtue of its replacement of nitrogen, would to some degree reduce the severity of nitrogen narcosis and decompression sickness. Although this is possibly so in theory, the scant experimental evidence that there is available, would suggest that oxygen actually contributes to nitrogen narcosis and decompression sickness.

The handling of gas mixtures, where oxygen or other gases are added to air, can produce some hazards. Oxygen increases the risk of fire and explosion.

Inadequate mixing can result in oxygen pressures being higher or lower than intended. This has implications regarding the safe dive profile.

Higher oxygen levels are also likely to produce a "build up" in the carbon dioxide transport in the blood. This has further implications as regards oxygen toxicity, nitrogen narcosis and possibly decompression sickness.

Oxygen enriched air or nitrox (EANx)

Most of the technical diving now performed involves the use of nitrogen/oxygen mixtures in which the oxygen concentration is greater than that of compressed air. Under these conditions it is very important to specify exactly how much oxygen is being used. Such phrases as 40-60 or 60-40 are not only confusing but often misleading. In Europe 40-60 is more likely to imply 40% oxygen, whereas in the USA it is more likely to imply 40% nitrogen.

The actual percentages used in technical diving do vary with different countries and establishments but the National Oceanic and Atmospheric Administration (NOAA) in the USA have chosen 36% oxygen and 32% oxygen as their two major mixes. These should not be referred to as Nitrox 1 or Nitrox 2, as this could also be misleading.

Any EANx diving has a safe depth range less than air due to neurological oxygen toxicity.

The oxygen pressures that are considered acceptable vary with different authorities, and in many cases there is a confusion between the neurological oxygen toxicity (which can result in nausea, vomiting, seizures, etc.) and respiratory oxygen toxicity, which tends to only occur with prolonged diver exposure. Many of the pressures being quoted in the literature refer to the oxygen pressures observed with re-breathing equipment, when the carbon dioxide levels were not being measured which complicates considerably the actual cause of symptoms. Most of the work carried out during World War 2, and soon after, failed to measure the carbon dioxide levels and therefore their conclusions regarding safe oxygen limits, are open to question.

NOAA states that the maximum oxygen pressure acceptable is 1.6 ATA. The National Undersea Research Centre in North Carolina recommends 1.45 ATA. The Swedish authorities have recommended 1.4 ATA and Dr Richard Vann of the Divers Alert Network has suggested 1.2 ATA. The US Navy give a much greater range, and relate it to the duration of the exposures.

The claimed advantages of EANx diving include a probable reduction in decompression sickness incidence, and a possibility of reduced nitrogen narcosis.

On a theoretical basis, presuming nitrogen pressure as the sole cause of nitrogen narcosis, a 20% oxygen mixture (air) at 23 m could be replaced with a 36% oxygen at a depth of 30 m. to give an equivalent "narcotic effect". Experimental verification for belief in this theory has be sought, but it was unable to be verified (Linnarsson, Bennett).

Although oxygen is used as a treatment to replace nitrogen, when the latter has caused decompression sickness, it has also been contentiously incriminated as a cause in its own right (Donald, Wethersby) or as a contributor (Thalmann) to this disease!

A common claim is made that there is less post-dive fatigue with EANx than there is with air. This has not yet been verified.

Low risk nitrox diving

It is possible to use EANx to obtain possible advantages, with relatively few disadvantages, under certain conditions.

In this type of technical diving, the nitrox mixture, usually 32% or 36% oxygen, replaces air, but the same equipment is used and the same decompression profiles permitted, within the 15-40 metre range.

It has been claimed there is deterioration in the dive equipment by using high oxygen mixtures but this has not been supported.

It is likely, because of the higher oxygen levels inhaled, that there will be a concomitant degree of carbon dioxide retention, based on the common and competitive pathways for the transfer of these gases.

Higher risk nitrox diving

In this type of diving (EANx) the profile of the dive is altered to make allowance for the high oxygen, lower nitrogen levels, based on the EAD or similar calculations. Thus the diver is likely to increase the duration of his no-decompression dive, reduce the decompression stops required or increase the duration or depth of the dive for the same decompression time commitment. Whether this calculation is justifiable under all conditions, has yet to be demonstrated.

The probable only genuine advantage of this kind of diving occurs if "air" stops are followed during decompression, whilst using EANx .

There is a possibility of an increased risk of decompression sickness, due to the effects of oxygen contributing to this disorder, or because of the use of untested algorithms used in commercial nitrox decompression profiles.

The "bent" diver is also more likely to have had a high oxygen dose, contributing to respiratory damage during the recompression therapy, than his air breathing colleague.

There may well be an alteration in the type of decompression sickness sustained with this form of diving because of the increase duration that it frequently entails. The slower half-time tissues are more likely to be affected, and this should be considered during the subsequent recompression therapies, and also the possible increased susceptibility to dysbaric osteonecrosis. The only reason for proposing this is that the dives, being longer, will influence the "slower tissues".

High risk. Helium and tri-mix diving

There are significant differences in the way the body handles helium to the way it handles nitrogen. Both are inert gases, but helium is much less dense and is also less soluble in some tissues than nitrogen. It does, however, have a much greater speed of diffusion and also conducts heat more rapidly.

The real advantage compared to nitrogen is that it does decrease the incidence of nitrogen narcosis. For dives in excess of 30-40 metres, the risks of nitrogen narcosis can be proportionately decreased as helium replaces nitrogen. It thus tends to be used for dives of greater depths. An additional factor is the reduction in breathing resistance due to its decreased density and other factors, also allowing dives to greater depths.

The effects on decompression sickness likelihood are more complicated. It is probably likely to produce less decompression requirement for the longer dives, but may well require more decompression for shorter dives. Many of the helium and Trimix decompression tables are less well validated than the air tables.

The main problem is that the divers are diving deeper with helium and Trimix than with compressed air and therefore are exposed to all the associated problems of depth (other than nitrogen narcosis and breathing resistance). Barotrauma and DCS risks are aggravated. The environmental difficulties associated with depth include poor visibility, buoyancy problems, excess gas consumption, stress factors and the increase risks and difficulties with first aid, rescue and resuscitation.

There is also a greater conductive heat loss from helium, even though there is some question regarding the respiratory heat loss. Heliox feels colder to breathe and in a helium environment the heat is lost more rapidly. Increased depth aggravates heat loss.

Voice distortion can produce communication problems. At greater depths the high pressure neurological syndrome (HPNS) also becomes relevant.

The difficulties with mixing gases, referred to above are also present with helium and are complicated by the different compressibility of helium, as well as the risk of ascending with low oxygen pressures, which are commonly used with deep helium diving.

Comparison with commercial deep diving is noteworthy. Experience has demonstrated the need for a surface supply of gas, full face masks, communication systems, a standby diver, a wet bell and a recompression chamber on site in order to reduce accidents to acceptable levels. The less trained amateurs appear to have no such requirements.

Very high risk. Rebreathers or circuit sets

Re-breathing equipment has been in use for more than a century, causing many deaths and cases of unconsciousness. Despite the recent electronic mechanisms, the essential problems of re-breathing equipment remain. It is very much a high risk strategy to employ for specific reasons, by professionals.

The value of re-breathing equipment is that it produces fewer bubbles and is therefore more silent. This is of use both in clandestine operations and for marine photography. It is more economical on gas, as the gas is recycled through the diving equipment, in a "circuit". It can also be constructed with low magnetic materials, which are useful if one is working around magnetic mines.

The main disadvantage that is inherent in all types of rebreathers is the failure of the carbon dioxide absorbent system to work effectively under all diving conditions. This may occur for many, many reasons, but includes an inappropriate canister design. There has been little genuine improvement in canisters over the last 30 years and they were inadequate then. It is surprising how few

RISK ASSESSMENTS OF VARIOUS FORMS OF TECHNICAL DIVING

Low risk nitrox diving

Using Nitrox (EANx) to replace air.
Same equipment as for air
Same profile as an air dive.
Range 15-40 m

Advantages

- Less risk of decompression sickness (DCS)
- Probably less nitrogen narcosis
- Reputed less post dive fatigue

Disadvantages

- Gas mixing, handling and correct usage
- Shallower maximum depth due to oxygen toxicity
- Reputed deterioration of dive equipment (?)
- Possibly more CO_2 retention

Higher risk nitrox diving

Using Nitrox (EANx) to replace air
Same equipment as for air
Profile for Equivalent Air Depth (EAD)
Range 15-40 m

Advantages

- Increased duration of no-decompression dive
- Or less decompression time (shorter stops)
- Or greater duration/depth of dive for same decompression
- If air stops are followed more efficient decompression (less N_2 on board)

Disadvantages

- Gas mixing, handling and correct usage
- Maximum depth limited by oxygen toxicity
- Possible increased risk of DCS (0_2 effect, untested algorithm)
- Possible alteration of DCS and recompression therapy (slower tissues affected by longer dives)
- Possible increase in risk of Dysbaric osteonecrosis (slower tissues affected by longer dives)

High risk. Helium diving

Helium is
- Less dense than nitrogen
- Less soluble than nitrogen
- Diffuses faster than nitrogen
- Conducts heat better than nitrogen

Advantages

- Less narcosis allows greater depth
- Less breathing resistance allows greater depth
- Less decompression for longer dives

Disadvantages

- Gas mixing, handling and correct usage
- Deeper diving possible
- Multiple cylinders of different mixtures needed for deep dives
- Longer decompression for short dives
- Heat loss to the environment and probably through the respiratory tract.
- Voice distortion interferes with communications
- High pressure nervous syndrome (HPNS) at great depths

Very high risk. Rebreathers

Advantages

- Economical
- Silent
- Can be non-magnetic if required

Disadvantages

- CO_2 toxicity
- Dilution hypoxia
- Caustic cocktail
- Deeper, longer dives increase risk of DCS

Oxygen rebreathers (closed circuit)

- Depth limit 8-9 m

Mixed gas rebreathers

- Semi-closed circuits have problems with oxygen supply vs oxygen usage
- Closed circuits depend on sensors to monitor and control oxygen levels
- Oxygen monitors can fail

improvements the manufacturers have included in the carbon dioxide absorbent canisters in the sets now being promoted.

Also, the absorbent itself is not always reliable. It frequently varies in efficiency and this should be tested with each absorbent batch. This is not feasible for the individual diver. The handling and storing of absorbent may result in deterioration in efficiency, as will the degree and type of wetting that may occur.

When diving in sea water, hypertonic saline can enter the system, causing a great reduction in efficiency. The absorbent itself, when combined with carbon dioxide, produces water as a by-product, which can also influence the efficiency. Also when water gets into the re-breathing set, it may collect some of the alkali from the absorbent and then may enter the divers mouth and lungs which can be very unpleasant. This is called a “caustic cocktail”.

The carbon dioxide absorbent must be packed correctly into the canister. This is an skill and requires training. The density of packing influences the efficiency. Lower temperatures also reduce the efficiency of the absorbent.

Often absorbent canisters will work very well at a moderate work load, but when exertion is required, the absorbent canister will frequently fail - especially if it has been in use for a considerable time.

The manufacturers claims regarding the safe duration of carbon dioxide absorption in their diving equipment are optimistic, seemingly being based on gentle swimming, and do not apply to emergency situations where the diver is exerting himself maximally (such as when swimming against a current, or trying to rescue and tow a companion, even on the surface).

The other big disadvantage is that any re-breathing set can produce a dilution hypoxia. Even those that use 100% oxygen can occasionally cause this, usually by incorrect technique of “clearing the set” (and the lungs) of inert gas. It can also occur if there is a small amount of inert gas in the gas cylinder, and especially so when there is a considerable amount of nitrogen or helium, such as with nitrox, heliox or tri-mix diving. It may be induced by an incorrect mix, a leak from the set or obstruction to the inflow, or loss of cylinder pressure.

Sometimes hypoxia will only be occur during ascent. The reduced oxygen pressure is acceptable at depth, but translates to a dangerously low oxygen partial pressure nearer the surface.

Rebreathers require specialised diving protocols, when rescue and resuscitation are needed. It is not just a matter of removing a mouthpiece and replacing it with another. Companion diver drill needs to be tailored for each type of rebreather.

The problems of gas mixing and handling also relate to this equipment.

Oxygen rebreathers are closed circuit sets, used to a maximum depth of about 8-9 m, usually restricted to Naval warfare and have resulted in many cases of unconsciousness and death. Occasionally photographers will use this equipment, but would be unwise to do so, as the companion rescue drill is often required.

Some rebreather sets have a constant flow of nitrox, heliox or trimix gas. They are usually semi-closed circuit sets. With these the oxygen level in the breathing bag or inspiratory tube will vary according to three major factors. These are the volume and mixture of the incoming gas, the energy utilised in metabolism (oxygen uptake) and the gas released as bubbles with ascent. The result is that the inspiratory oxygen range can be a variable quantity which makes the equipment much less safe. The interaction between the input and output of oxygen will result in a variable oxygen percentage and ascent or descent will determine the oxygen pressure. These sets are especially likely to cause dilution hypoxia and hypoxia of ascent.

As hypoxia usually produces no warning before it causing unconsciousness, the use of constant flow rebreathing sets would be considered very unwise. Close attention to the cylinder pressure, ensuring an adequate inflow of gas, and flushing with fresh gas before ascent is essential

The more expensive closed circuit rebreathing sets use sensors to measure the oxygen pressures during the dive and a feed back system adds oxygen or a diluent gas (nitrogen, helium, mixtures), as required, to ensure that the oxygen partial pressure remains within a certain range. This equipment is extremely expensive, often not reliable and should only be used by those with excessive faith in technology.

Anyone who uses a rebreather without a full face mask, being aware of the much greater risk of unconsciousness and subsequent drowning, has got to be stupid and deserves everything they get.

Conclusion

Perhaps the most important thing about Technical Diving is to realise that the majority of the diving deaths that occur in recreational divers occur for reasons which will be aggravated by the use of more complex equipment, in more hazardous environments. Technical diving is therefore, by its very nature, likely to have greater risks than normal recreational diving, other factors being constant.

The margin for error in this type of diving is appreciably less, and therefore it should only be employed by divers with enormous experience, detailed training and meticulous attention to equipment and its use. The advocates of technical diving tend to lay great stress on aspects of safety which are relatively unimportant. They will stress the importance of decompression sickness, and the physiological advantages of oxygen, but will ignore the more frequent causes of diving deaths, such as exhaustion of gas supply, buoyancy problems, stress responses, etc. They will also tend to ignore the areas in which the "technical advances" have been meagre, e.g. the efficiency of carbon dioxide absorbents, in preference to high-tech oxygen sensors and theoretical decompression algorithms.

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DEEP DIVING; THE LIMITS ?

Rob Palmer

Key Words

Deep diving, safety, technical diving

Technical diving expert Rob Palmer believes that the frontiers of deep, mixed-gas diving are being reached, and that the new areas opened up need to be mapped and made safe. He also argues that divers who die in the pursuit of records, or mere fun, are to be mourned less than "serious explorers".

Over the past two years or so, the expansion of sport diving beyond its traditional boundaries has gathered momentum. Gradually, the relatively new territory of what has variously been called extended range or technical diving has been explored.

Of course, only a relatively small minority of divers have actually taken part in this process (most have, quite rightly, no interest whatsoever in doing so). But while such an upsurge of discovery can be of benefit to diving as a whole, feeding new techniques and expertise into the sport, it can also unleash all the considerable risks and problems that invariably accompany such exploration. What I mean by this is that all unexplored territory has its danger zones.

Technical diving is rapidly reaching the sensible frontiers of its first expansion. A few individuals are besotted by the glamour of record breaking depths and durations and many other practitioners are beginning to wonder what to do with their new-found expertise. The former are, frankly, dangerous. There is absolutely no point in going to great depths, using either open- or closed-circuit scuba, simply for fun.

The practical limit of self-contained diving is around the 75-80 m mark in temperate waters, and perhaps 100 m or so in tropical waters. Depths beyond these can be reached only by engaging in a sort of peculiar Russian roulette, akin to putting an increasing number of bullets into an automatic and pulling the trigger for an increasingly longer time.

Of course, plenty of people have been to far greater depths than we, as self-contained divers, can. But they have had good reasons for doing so. And they have used appropriate technology, one atmosphere systems such as the Newt Suit, small manoeuvrable submersibles such as Deep Rover or the new Deep Flight or expensive saturation support systems. That sort of technology goes with the territory.

Flesh and bone have no place unsupported beyond 120 m. Not yet, anyway. I am not saying that technology will not evolve to the point where we can breathe the necessary gases from the water and biologically engineer ourselves to cope with the environment. Such things may be possible one day, but they are not possible yet.

The thing about technical diving is that every time new frontiers are set, the territory they bound has to be explored before it can be made safe. This is what the next stage of technical diving will be about, the safe "mapping" of the areas within the new frontiers.

Currently, we can shorten decompression by using oxygen-enriched mixtures, but we cannot eliminate it. We can virtually banish narcosis by using trimix and heliox-based mixtures in open, semi-closed or closed circuit systems, but this comes at the price of extended inert gas intake and longer decompressions, requiring more complex use of different gases to bring us back to the surface in a reasonable time.

We can reduce the effects of temperature by looking properly at insulation and drysuit construction, and at passive heating systems that warm from inside out, but hypothermia is still a problem on long deep dives in non-tropical waters.

With all these new freedoms come new limits, and we have to learn what these are before we can understand how to cope with them. For instance, it is no good using heat packs or electric undersuits to heat the body extremities when it is the core you have to keep warm.

This is where attitude of mind comes in. To be a good explorer, you have to have an aim. The best explorers come back to share their findings with others. Explorers who go places simply for fun are the dilettantes of the genre; they do not give back to the system. They are tourists, visiting, looking, but not really appreciating the full potential of the experience.

To be a good technical diver, it is necessary to appreciate the fact that there are limits and to understand that there are sound physiological reasons for many of these. For instance, the human frame has evolved to work in a narrow range of temperatures and in pressures centred around 0.21 bar oxygen and atmospheric pressure.

While there are times when it is convenient to have human eyes and human hands at 150 m or more, getting there and getting back safely can become as complicated as the task itself, and once this is the case, the reason for actually being there needs to be a very good one. That is when it becomes worthwhile having the luxury of saturation systems, whether you are working on surface-supplied gas reclaim or untethered closed-circuit.

While there is a breed of self-styled technical diver who is, essentially, irresponsible, who sees the setting of records and the wearing of the gear as mere fun, there are others who see the crossing of personal frontiers as meaningful, and who devote their lives to them, adding input to the system as they do so. Do not confuse the two.

Neither is immortal; but the passing of the latter is to be mourned more than that of the former. The shock to the diving community caused by the recent death of experienced American technical diver Sheck Exley was far greater that would have attended the passing of a diver foolishly exploring territory he was neither experienced enough to explore nor trained to be in. Internationally, there have been several deaths this year which fall into the latter category (though far fewer than in, say, British winter mountaineering) and they have barely caused a ripple, other than to contribute to the argument of a vocal minority who say all such technical diving should be banned.

This is why we need to see the right attitude developing in technical diving. That is what most of us who started to teach the new boundaries were trying to get across: learn new skills, develop experience and go there for a good reason. Carefully.

Developing experience is one of the key areas. For all any course will teach you is a basic understanding of the skills covered by that course; there is not a diving course in the world, recreational, commercial or technical, that will turn you into an instant expert, whatever the brochures say. Experience comes by doing it and such experience can be painless or painful depending on how, and how quickly, you try to undergo it.

I had dinner with Sheck Exley in New Orleans in January (1994) a few weeks before his death at a depth of over 900 ft in a Mexican cave resurgence. We talked about this very thing, this attitude problem, this “strutting of stuff” by some of the new generation of technical divers that was in danger of bringing the discipline into disrepute.

Exley summed it up pithily. “They ain’t seen the varmint”. What he meant was that there was a whole group of people out there who had learned all the skills to take them to 80 m and back on a good day, but who had never looked fear straight in the face when things went wrong. Unfortunately, some of this generation are now rushing into being instructors, full of the enthusiasm of exploration without having experienced the dangers. It is a long way back from 80 m in a dark sea when Murphy is at your shoulder and you are cold and tired and scared.

That is what worries me about technical diving. Not that it is too dangerous to dive to 80 m, or too difficult to remember which regulator offers which gas and when to change mixtures, or the crushing boredom of a long cold decompression in an open sea. All of these are manageable on a good day, when Murphy is making someone else’s life miserable. People do things that are just as dangerous, if not more so, all the time. On horses, up mountains, in racing cars, hang-gliders and motorcycles....

What worries me is the instant expert straight off a bad course, or no course at all, who has no idea that fear even exists, much less what it looks like, who buys all the gear and sets off on some personal underwater crusade.

It matters that you know what fear looks like. It matters that you carefully develop the *experience*, as well as getting the training and buying the equipment. And you can start by developing the right attitude, whatever depth you dive to. It is the attitude that helps tame the varmint, that keeps Murphy from getting out of control. And it matters that you know when to stop, to be happy with the new territory and help map it. There is something very mature about accepting personal boundaries and knowing when to go no further.

So what are we left with?

There is an enormous amount of new territory to explore. The top 100 m of ocean gives us access to most of the continental shelf, and a “soft” 75-80 m limit in northern European waters places a lot of unexplored territory within reach. New wrecks, drop-offs, pinnacles, hundreds of square kilometres of ocean floor to discover. Be happy with that.

Meanwhile, let the serious technical divers get on with their own thing, and do not condemn them for their ambition. There is nothing wrong with extending personal boundaries for good reason. It is what brought us out of the trees, and it is what has taken us to the moon. But please do not encourage the “tekkie” who struts his stuff in all the latest gear and brags about how deep he is going to dive.

At the time he wrote this article Rob Palmer was a Director of Technical Diving International (Europe), one of the leading technical diving training companies.

Earlier this year (1997) he failed to return from a routine dive in the Red Sea. For some reason unknown he sank steadily after entering the water. His companions could not reach him and his body was never recovered.

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NEW WAVE AND TECHNICAL DIVING
WOT WE NEEDED WAS NITROX

Ian Skelton

Key Words

Nitrox, technical diving.

Ian Skelton recalls the frustrations experienced by members of Plymouth Sound BSAC, investigating a 200 year old wreck with air in their tanks. Nitrox gives them longer bottom times on their 33 m dives to the vessel.

Squeezed side by side between walls of silt, my buddy and I excavate among the collapsed timbers of the 200-year-old brigantine. Our airlift, rising vertically between us, spills plumes of sediment down tide. The time passes quickly but, like all good amateur archaeologists, we resist the urge to dig faster. Unlocking the secrets of the Metta Catharina is not something to be hurried.

In disbelief, I stare at my computer. Twenty-six minutes at 33 m. We have four minutes left before we must drag ourselves away.

My reverie is broken by a Jaws-like grip on my arm. My buddy is pointing at something glinting in the dark weal of silt. I spot the lower half of a wine glass, its fluted stem set alight by the nodding beams from my buddy's helmet lamp. A tingle of excitement passes between us like static electricity. Three minutes later our gently probing fingers signal the bad tidings: the bowl of the glass is trapped. It will require several more minutes of careful work to free it, and our time is up.

Disappointed, we endure the usual tedious deco hang on the lazy shot. I soon become bored with counting holes in my buddy's gloves, and instead, reflect on our situation. Diving regularly on the wreck site of the Metta Catharina, we suffer a recurring problem, too little bottom time and too much deco. My mind reaches back to things I have heard and read recently about that wonderful new gas, nitrox. New? This gas has been around since a certain Mr Beddoes started tinkering with it in 1794.

Enriched air nitrox (EANx), was first used for diving during the pre-WW I era. In those far off days German and British diving and engineering companies experimented with breathing mixtures that would reduce the amount of nitrogen in air and so reduce the decompression commitment at shallower depths.

Generations later the National Oceanographic and Atmospheric Administration (NOAA) became aware of the significant benefits offered by nitrox. They published tables and procedures for its use in their 1979 diving manual. More recently the scientific and advanced level sport diving community have increasingly begun to utilise the advantages of nitrox.

Which brings us to the present, and the decision of the BS-AC to give a green light for the use of nitrox in Branch activities.

My chilled digits claw for the slate on the lazy shot, and I scribble a barely legible message: "Wot we need is nitrox!" My buddy nods furiously. Nitrox is firmly at the top of the agenda at our next Archaeological Section meeting.

The Archaeological Section of our Club, Plymouth Sound BS-AC, was founded way back in June 1973. Our brief at that time was to locate and investigate ancient wrecks in the Plymouth area. Success came quickly. In October of that year we found the wreck site of the Danish brigantine Die Frau Metta Catharina von Flensburg. Blown into Plymouth Sound during a severe gale on 10 December 1786, the 122 ton vessel was en route from St Petersburg for Genoa laden with a cargo of reindeer hides. She struck a reef off Drake's Island and became a total loss.

Buried in dense black silts in the deep-water channel of Plymouth harbour, the Metta Catharina's final resting place was marked only by her bronze bell and a thin scatter of cargo. During a pre-disturbance survey we discovered that most of the reindeer hides remained intact tightly jammed together deep within the vessel's two main cargo holds.

When excavation began, some of this wonderfully preserved cargo was sold to help fund the archaeological project. For this generous concession the team members will always be grateful to the Metta Catharina's present day owner, His Royal Highness Prince Charles.

Working the wreck site to current archaeological standards is a painfully slow process, not helped by poor underwater visibility, contrary tides, and above all by the depth, 29-34 m.

It was because of this depth problem that I believed nitrox should be addressed, and I had no reservations about advocating its use to the lads in the Archaeological Section. In 22 years, the lads have never been slow to adopt new ideas and practises, especially where new safety measures are concerned.

At our nitrox meeting, we were lucky to have along as our guest speaker Paul Dart, a senior instructor from Fort Bovisand Underwater Centre. Silence reigned as Paul began detailing the catalogue of benefits we would enjoy if we started to use nitrox. When he pointed out that by using Nitrox 32 (32% oxygen), we would be working at an equivalent air depth of 6 m or so shallower than the actual diving depths, the silence was broken by the lads in the team clamouring for the date of his next course.

Paul obligingly set up a special course for us, structured to run over two evenings. Run under the banner of the International Association of Nitrox and Technical Divers (IANTD), there was a choice between Basic Nitrox, Advanced Nitrox, and Technical Nitrox courses. We opted for the Basic Nitrox.

Planned as a theory-only conversion, it covers matters such as the history and use of nitrox, oxygen physiology, use of decompression tables, gas law revision and basic nitrox equipment handling. A short theory exam wrapped up the sessions. We walked away from Fort Bovisand as fully fledged "Nitrox Divers" with certificates to prove it.

It was time to put the theory into practice. Fortunately, Sandford and Down, Plymouth's oldest established dive shop, had recently made a substantial investment in the new technology needed for nitrox. They very swiftly made the necessary adjustments to our gear. Our cylinders were modified, cleaned and labelled, demand valves were modified and cleaned and the supply of gas was made readily available. All we were required to do was analyse our own mixes. We chose to all stick to 32% oxygen, which at our maximum operating depth of 34 m, would give a partial pressure of oxygen, (PPO_2) of 1.41 bar, comfortably inside the IANTD recommended limit of 1.5 bar.

We have now carried out 6 nitrox dives on the wreck site of the Metta Catharina. The team's enthusiasm for the gas remains unabated. Certainly, no one is talking about going back to air. But neither have they any illusions about nitrox. We are well aware of its limitations and dangers.

However, the benefits are only too evident. Still working within our given depth range, our safety margins have improved, we have longer bottom times and less time spent hanging in mid-water.

The equivalent air depth of Nitrox 32 at our normal maximum working depth of 33 m is 27 m. This means that a 30 minute dive requires a decompression stop of 1 minute at 6 m. We could stay down for an additional 4 minute without requiring a longer stop. This means that we are well inside the limits of the BS-AC '88 tables. An air dive (Nitrox 21) to the same depth would require a stop of 3 min at 6 m. With the average age of the diving team hovering at a near geriatric mid-forty, our only regret is that we waited so long to use a gas which is almost as old as the wreck of the Metta Catharina herself.

From January 1996, BS-AC nitrox courses will be available at a basic level, dealing with no-stop diving; and advanced level, using nitrox as a decompression gas.

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GLEANINGS FROM MEDICAL JOURNALS

DECOMPRESSION ILLNESS AND DEATHS

US Navy decompression illness and fatalities 1990-1995. Patterns and trends.

Howsare CR, Jackson RL, Rocca AF and Morrison LJ. *Undersea Hyperbaric Med* 1997; 24 (Suppl): 22

Abstract

Background

The Naval Safety Center (NSC) collects data for the Navy diving programs. The data, with collection driven by mandatory reporting requirements, provides and excellent database for population based studies.

Methods

The NSC collects every Navy dive, fatality and DCI case. A user friendly computerised Dive Reporting System coupled with mandatory reporting requirements enforced by regular safety inspections ensure reasonably complete information for Navy diving. Structured diving incident reports help to standardise DCI reporting. The entire NSC Navy diving database for 1990-1995 was analysed for quality and was examined to look for patterns or trends.

Results

There was a peak in the total number of dives in 1992 (N=124,972), then a steady decrease with a lowest number in 1995 (N=70,655) giving a total of 648,488 dives for the 6 year period. The fatality rate was about 1 per 100,000 dives. Analysis of each DCI narrative report (N=382) demonstrates an over reporting/misdiagnosis rate of 32%. Adjusted DCI rates for the 6 year period shows per 10,000 dives an AGE rate of 1.3m a Type 1 DCS rate of 1.3 and a Type 2 DCS rate of 1.3. The highest DCI rates were in 1990 and 1991 with research dives resulting in DCS

accounting for the higher percentage of the cases. Fatalities were equally distributed across the period and the misdiagnosis rates highest in 1990 (39%) and decreased over the period to a low of 23% in 1994 and 1995.

Conclusions

US Navy diving is comparatively safer than recreational scuba diving given the very rough fatalities in Bennett and Elliott's text. Unlike most diving databases, over reporting/misdiagnosis of DCI in the US Navy's is common. With the relatively small number of DCI cases per year an aggressive diving research program or a long, deep salvage operation could skew annual DCI rates.

From

Naval Diving and Salvage Training Center, Panama City, Florida 32407, USA.

Key Words

Accidents, deaths, decompression illness, occupational diving.

Does the dive profile affect the manifestations of decompression sickness?

Ball R, Temple D, Survanshi SS, Parker EC and Weathersby PK. *Undersea Hyperbaric Med* 1997; 24 (Suppl):22

Abstract

Background

The relationship between the dive profile and manifestation of DCS symptoms and signs has never been studied in a large number of human cases in which accurate information about the dive profile and DCS manifestations has been recorded.

Methods

We reviewed the records of the NMRI Decompression Modelling Database and selected over 4,400 sing air or nitrox dives that were conducted in laboratory settings by the US, Canadian or UK militaries between 1949 and 1994. DCS cases were divided into those involving pain or neurological manifestations. We conducted univariate analyses of the effect of depth, bottom time and ascent rate on the proportion of neurological cases. Ascent rate was calculated as the mean ascent rate for no-stop dives and the mean ascent rate to the first stop for dives with decompression stops.

Results

There were 232 cases of DCS: 117 with pain only, 39 with both pain and neurological symptoms or signs, 14 with only neurological symptoms or signs and 2 with only other manifestations. There was a higher proportion of neurological cases (35% vs 18%) when ascent rates were faster than 55 fsw(16.6 m)/min ($p<0.01$). There was a higher proportion of neurological cases at depths > 40 fsw (12 m) (24% vs 10%). The statistical significance in these cases was only marginal($p=0.07$). There was not a higher proportion of neurological cases on dives with short bottom times.

Conclusions

Faster ascent rates and deeper depths tended to be associated with more neurological cases, but the associations were of marginal statistical significance. Only with large numbers of accurately collected dive profiles and DCS case information can the question be answered definitively.

From

Naval Medical Research Institute, Bethesda, Maryland 20889-5607, USA.

Key Words

Ascent, decompression illness, hyperbaric research.

The role of technical input in the investigation of fatal diving accidents.

Calder IM. *Undersea Hyperbaric Med* 1997; 24 (Suppl): 26.

Abstract

Background

Many fatal diving accidents are marked by the end stages of complex physiological changes. These may be further compounded by therapeutic intervention. The use of a multi-disciplinary team may allow an easier solution of a complicated equation.

Methods

A review of 127 professional and amateur diving accidents has shown that 17 were able to be moved from a speculative to a certain cause of death. The fact of drowning in an experienced, trained and disciplined diver suggest more than a simple explanation, especially when human factors have been eliminated. Most biochemical parameters after death are of little value and may be actively misleading. However toxicology per se must be regarded as an important component. The time sequence in fatal diving accidents rarely allows histological changes to take place and at the best morphological changes may be modified by gas artefact. In broad terms the cause of death (other than by trauma by gas) may simply be resolved into a spectrum of anoxia/asphyxia/drowning or hypothermia. It is at this stage that technical input can be of vale and various scenarios evolve.

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