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To provide information on underwater and hyperbaric medicine.
To publish a journal.
To convene members of the Society annually at a scientific conference.

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Abstracts are also required for all case reports and reviews. Letters to the Editor should not exceed 400 words (including references which should be limited to 5 per letter).

References

The Journal reference style is the "Vancouver" style, printed in the Medical Journal of Australia, February 15, 1988; 148: 189-194. In this 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 EDITOR'S OFFERING

In this issue are two papers on oxygen used underwater which have important implications for all divers. First Carl Edmonds discusses the development and history of underwater oxygen treatment for decompression sickness (DCS). At first an alternative to medical evacuation (medevac) from remote locations or the transport of a chamber to the patient, it provoked intense resistance among the diving establishment, which in those days was almost all naval officers, who believed that the right thing to do for decompression sickness was to recompress as soon as possible. They, however, wore intellectual blinkers being heavily influenced by the less successful outcomes of decompression sickness when using in water recompression on air. Air recompression tables were much longer than their successors, the oxygen tables, and problems of cold and increased gas loading were common when using air to recompress in water. So although the Australian experiment would allow rapid recompression the one track thought process, recompression in the water did not work, could not allow it to be used although it was only the last part of the Australian, high oxygen, tables, 9 m to the surface, which had a better track record than the USN air tables. However successful use of the underwater oxygen tables around the Pacific and Australia, combined with a similar approach to oxygen by the French, who found that many patients with DCS treated with aspirin, fluids and 100% oxygen during their ambulance ride had lost all their symptoms and signs by the time they arrived, after some hours in the ambulance, at the recompression facility. Such is the power of suggestion that the credit for this improvement was attributed, on theoretical grounds, in some large part to the use of aspirin, which some well known diving doctors adopted as a preventative measure before they dived.

No one now takes an aspirin the morning of going diving. And with the spread of chambers around Australia and the Pacific islands has returned a reluctance to accept that underwater oxygen treatment for DCS could be as good as evacuation and treatment in a chamber, even when the delay before treatment is factored into the equation.

The second paper on oxygen was presented at the Safe Limits Symposium in Cairns in October 1994 by Bob Wong. Pearl diving has been an extremely hazardous occupation ever since its inception in the 1880s. The cemeteries at Broome and on Thursday Island have, between them, hundreds of divers' graves, killed by decompression illness. In the earlier years of this century those who survived with paraplegia died from bed sores and urinary infection some months to years after being "hit". This was their fate until the introduction of antibiotics. The studies of the diving practices of the Torres Strait pearl divers, which formed the basis of Brian Hills' thermodynamic theory of decompression, showed that they did their first stops very deep around 21m or more. They did not decompress for as long as the USN tables would have required and they did get decompression sickness. But they did not have as high a rate of DCS as one would have expected from their shortened decompression times. It was postulated that their deep stops allowed them to off-gas without forming bubbles, while the shallower stops of the USN tables allowed bubbles to form on the first pull to a relatively shallow depth and the stay at that depth merely allowed the bubbles in the blood to be excreted from the lungs and may have prevented too many more bubbles forming. The word pull was accurate. These men were using brass helmets and, with the better employers, standard dress canvas suits. To stay on the bottom they needed a lot of lead to counter the buoyancy of the helmet. They had to be pulled up to the stage on which they stood to decompress. When trying to become buoyant it was fatally easy to get "blown up", the suit filled with air and the diver went rushing to the surface, arms and legs held rigid by the inflated suit. Some pearl divers were expected to work without the suit, which avoided the problem of blow up, but introduced those of cold and air embolism. If a diver bent over the air came out of the helmet. Inadequate air pressure, from the boat, allowed the water level to rise in the helmet. When the water rose to nostril level an inexperienced diver would hold his breath, duck out of the helmet and head for the surface.

There is no doubt that diving with a surface supply and a demand regulator, with a bail out bottle for emergencies, reduces the risks of uncontrolled ascents. But it increased the likelihood of DCS. Pearl divers are paid for time underwater and off work with DCS means no income, so there is a large financial inducement to put up with the minor symptoms of DCS. Paralysis cannot be hidden however. It would appear that since the introduction of underwater oxygen treatment for DCS in the pearling industry, and especially since the adoption of underwater oxygen decompression for some of the dives, that the occurrence of serious sequelae has decreased. It may be that the use of a slow ascent rate and underwater oxygen during decompression on deeper dives actually does prevent bubble formation and so DCS. Or it may be that prompt treatment converts a potential paraplegia to a symptomless individual. Pearl divers developing any symptoms after a dive are classified as having the "niggles" and treated. Few have residual signs or symptoms after their treatment. These get classified as DCS and recorded as such.

This practice is again something that the diving establishment disapproves of. But if it reduces the occurrence of permanent damage to divers in the pearling industry should it be condemned or encouraged ?

ORIGINAL ARTICLES

UNDERWATER OXYGEN TREATMENT OF DECOMPRESSION SICKNESS A REVIEW

Carl Edmonds

Abstract

The problem of decompression sickness (DCS) in remote areas is described with particular reference to the Indo-Pacific islands. The various approaches of medevac, surface and underwater oxygen (UW O_2) are addressed and the techniques and equipment used in underwater oxygen are documented.

The favourable experience with the original UW O_2 tables are compared with the less conservative, more hazardous, oxygen decompressions used by abalone divers and the shorter but successful exposures of the pearl divers. The latter imply that, with very prompt treatment, the 9 m oxygen treatment may be reduced in duration.

Background

Treatment of decompression sickness (DCS) in the mid 1960s involved recompression with air, at a minimum depth of 30 m and more frequently at 50 m.

The first case on which I was consulted was another diving physician who had, that day, treated another diver in the chamber. The fact that the diver/patient got moderately better and the physician got "bent", did not inspire confidence in the treatment tables. Nor did a review of the success of other cases treated.

Australia had one established recompression chamber (RCC) capable of applying the conventional treatments, in Sydney, at the Royal Australian Navy (RAN). We were therefore committed to the diving medical cover for all civilians as well as service personnel.

Our catchment area covered a radius of about 5,000 km and included many excellent diving sites, but often with primitive diving and aviation facilities.

The air table failures were presumed to be a consequence of getting civilian divers many hours or days after the symptoms had developed and the pathology stabilised. This was possibly not the experience of other organisations, such as where commercial divers could be treated immediately.

Medevac

The RAN and RAAF accepted responsibility for treatment of civilians in 1965, in lieu of any alternative, from most of the surrounding Indo-Pacific region. From 1968, to reduce the delay if the diver was significantly injured, we were as likely to take all the equipment (chambers, oxygen, appliances, etc.) to him, as we were to bring him to the chamber. It all depended on which was the quickest. We preferred RAAF Hercules aircraft, pressurised to sea level (1 atmosphere), for transport.

Only serious cases warranted medevac from such distances. The SOS decompression meter contributed to the unacceptably heavy case load during the early 1970s.

Surface Oxygen

In 1968 we started using oxygen while awaiting recompression, during the inevitable delays. The diver would receive oxygen in transit to the chamber, or he would be placed on oxygen while we brought the chamber to him. This decision was based on the writings of Paul Bert[1], and some unpublished experiments with guinea pigs. Most clinicians who used this first aid regime, in both Australia[2] and France,[3] seemed to be impressed with its success. It is now internationally accepted.[4]

Oxygen tables

Fortunately, in 1965, Goodman and Workman[5] produced their oxygen tables, allowing us to start treatment of almost all DCS cases at 18 m. These really only became used, with seriously ill divers, in about 1967. The oxygen treatments were also inadequate in many cases, possibly because of the delays and the development of complex pathophysiological changes only now being elucidated.[6]

That was when we decided to experiment. If a patient got worse during treatment, then the treatment was modified for that type of case. We capitalised on the beneficial effects of both pressure and oxygen without preconception. We took the usually severely ill diver to the shallowest depth that produced a satisfactory (but not necessarily complete) clinical response, i.e. one assessed as not to lead to permanent sequelae. We then decompressed with the maximum oxygen that would not produce convulsions. Each depth range had its own acceptable O_2 %, which was achieved by mixing air with 33% O_2, 40% O_2, 60% O_2 or 100% O_2. Dramatic treatment for a serious illness.

Those were called the Australian tables[7] and I would still revert to them for serious cases (not the indefinite cases with "soft" signs that now seem to predominate). We even avoided air breaks as we saw little value in perpetuating a nitrogen problem; also it seemed some patients deteriorated at or soon after the air break. We later used heliox to reduce the occasional respiratory oxygen toxicity.

The UW O_2 tables introduced soon after this, were no more than the shallow part of these "Australian tables", from 9 m to the surface.

This segment was frequently used in the RCC to treat;

very recent cases (e.g. those who developed DCS from the navy chamber),

minor cases of DCS,

those in which we were not convinced of the diagnosis, and

very delayed stable cases e.g. musculo-skeletal DCS, days after the dive (these responded equally well to surface oxygen).

Independently, the French developed their Comex tables,[8] which were a middle ground between the formal but very limited US Navy tables and the more flexible and thus complex Australian ones. The 9 m UW O_2 table differed little in effect from the subsequent COMEX 12 m RCC table

Underwater oxygen treatments

This was developed in the late 1960s at the RAN, and by 1970 was employed through many parts of the Indo-Pacific,[7] where chambers were not readily available. The reason I attest no doubt regarding the origin of this treatment, is that no one else seemed to be prepared to share the flack when the knowledge of our techniques spread to the USA in about 1973 or when reported at an international conference in France, in 1978.[9]

The UW O_2 regime is still employed by many divers in remote areas, such as in the Pacific islands, the abalone fields of southern Australia, and the pearl fields of the Australian north. But variations in technique have developed. In Hawaii they have combined it with their UW air techniques, producing a deep air dip followed by the UW O_2 regime. I have no experience of this last modification, but I can elaborate on the others.

The UW O_2 treatment is now a part of many national diving manuals. It was included in the Royal Australian Navy manual as tables 81 and 82, but took 15 years and a some modifications, before it found its way into US Navy Diving Manual.

Rationale

The value of substituting oxygen for air in the recompression chamber treatment of DCS, is now well established. The pioneering work of Behnke, Yarborough and Shaw,[10,11] over 50 years ago, eventuated in the oxygen tables produced 30 years ago.

The advantages of oxygen over air breathing include: increasing nitrogen elimination gradients, avoiding extra nitrogen loads, increasing oxygenation to tissues, decreasing the treatment depths and exposure time, reducing vascular/haematological damage, and improvement in overall therapeutic efficiency. The same arguments are applicable when one compares UW O_2 and UW air treatments.

Certain other advantages of UW O_2 over underwater air are obvious. Attendant divers are not subjected to the risk of DCS or nitrogen narcosis, and the affected diver is not going to be made worse by premature termination of the treatment, if this is required. Hypothermia is much less likely to develop, because of the greater efficiency of the wet suits at these depths.

The underwater site chosen can often be in a shallow protected area, reducing the influence of adverse weather on the patient, the diving attendants and the boats. Communications between the diver and the attendants are not difficult, and the situation is not as stressful as the deeper, longer, underwater air treatments or even as worrying as in some 3rd World recompression chambers.

Technique

Whenever oxygen is given , the cylinder should be turned on and the flow commenced, before it is given to patients or divers to breathe.

Oxygen is supplied at maximum depth of 9 m (30 ft), from a surface supply. Ascent is commenced after 30 minutes in mild cases, or 60 minutes in severe cases if significant improvement has occurred (this time may be extended for another 30 minutes if there has been no improvement). The ascent is at the rate of 12 minutes per metre or 4 minutes/foot. After surfacing the patient should be given periods of oxygen breathing, interspersed with air breathing, usually on a one hour on, one hour off basis, with respiratory volume measurements and chest X-ray examination where possible.

Equipment

No equipment should be used with oxygen if it is contaminated, dirty or oil lubricated.

The equipment required for this treatment includes the following: a large oxygen cylinder (e.g. 220 cubic feet (7,000 litres), G size). This is usually available from local hospitals, although in some cases industrial oxygen can be used from engineering workshops. Breathing this oxygen at a depth between 9 metres (30 ft) and the surface, for this duration, is usually insufficient to produce either neurological or respiratory oxygen toxicity. A 2 stage regulator, set at 550 kPa (80 psi) and fitted with a safety valve connects with 12 metres (40 ft) of supply line (HP hose). This allows for 9 m depth; 2 m from the surface of the water to the cylinder, and 1 metre around the diver.

A non-return valve is attached between the supply line and the full face mask (e.g. a Cressie-Sub). The latter is inexpensive and enables the system to be used with a semi-conscious or unwell patient. It reduces the risk of aspiration of sea water, allows the patient to speak to his attendants, and also permits vomiting without obstructing the respiratory gas supply. The supply line is marked in distances of 1 m from the surface to the diver, and is tucked under the weight belt, between the diver's legs, or is attached to a harness. The diver must be weighted to prevent drifting upwards.

A diver attendant should always be present, and the ascent controlled by the surface tenders. The duration of the 3 designated tables is 2 hours 6 minutes, 2 hours 36 minutes and 3 hours 6 minutes.

The treatment can be repeated twice daily, if needed. Some experienced divers use an oxygen re-breathing system. Recreational divers tend to prefer oxygen from a (well marked) designated scuba.

Experiences with UW O_2

Apart from the original trials with UW O_2 (see Annexe A and references[7,9,12]) most of the cases known to me come from 3 very different diving communities:

TROPICAL ISLAND DIVERS

There is no way of knowing the number of cases treated on the tropical islands of the Indo-Pacific. Some areas, with which I am more personally associated, have advised me of dozens of such cases in each of the following localities; Solomon Islands, Papua New Guinea, Rabaul / Kimbi, Torres Strait Islands.

I am aware of other areas because of; the cases referred back to me, if they reside near Sydney, or where I have been directly involved in the treatments (Christmas Island, Lord Howe Island, the Cook Islands, Nauru, Truk Lagoon and other areas of Micronesia and the Great Barrier Reef). I am aware of only one accident during these treatments, but the aetiology is problematical. See Annexe B.[13]

AUSTRALIAN ABALONE DIVERS

In 1985, of the 200 or so registered professional abalone divers of Australia, 152 were submitted to a diving questionnaire, personal history taking, physical examination and various investigations.[14]

These divers were exposed to excessive diving durations, and 58% of them routinely employed a dive profile which required some form of decompression, according to the US Navy Tables, but which was omitted.

Although they employed repetitive diving, and some multi-level diving, this was frequently not in the manner usually recommended. On the contrary, the dives tended to be deeper as the day progressed, with deteriorating sea conditions. Also the water temperature was often cold (4-10 C).

At that time there was considerable ignorance in the field, as regards the UW O_2 techniques being employed by the RAN School of Underwater Medicine. Indeed, the few ex-RAN divers that were working as abalone divers at the time were usually a source of mis-information, having only been exposed to the conventional oxygen treatment tables used in the recompression chamber. A popular belief evolved that oxygen could be safely used at 18 m, as long as it was used for treatment.

Oxygen was rarely used for decompression per se, without decompression sickness, at that time. It had a poor reputation and the majority of the divers neither employed oxygen as a treatment nor had it on the boat. However, 8.6% had used oxygen for treatment on the surface, 7.9% also used it at a depth of 9 m or less underwater, 5.3% also used it at a depth greater than 9 m underwater. No diver used it in excess of 18 m.

Of the 625 cases of DCS that could be remembered by the 152 divers, 11% were treated in a recompression chamber, of which over half were neurological DCS, 15% were treated on the surface, with O_2, 66% were treated underwater, on air and/or oxygen and 22% were not treated at all.

These figures are probably not accurate, because of the inevitable vagaries of memory and denial.

The DCS incidence is especially misleading, as many of the divers would complain of joint and other symptoms after diving that they would not attribute to DCS. As a general rule, they would ignore minor symptoms, without considering them to be DCS, or they classified them as "niggles" so not requiring any activity.

Problems with oxygen toxicity are documented in Annexe C. Note that all of these cases were using oxygen at much greater depths than recommended (>15 m).

An informal survey was undertaken by letter (it is not easy to obtain replies from this occupational group) to ascertain the current status of UW O_2. After the 1985 Abalone Diver Survey, in which the UW O_2 regime was described, it would have been rewarding to report a safer oxygen use. Unfortunately this is not so. It has now superseded underwater air treatments, and is used frequently.

Although most of the deeper divers (18 m+) now routinely carry and use oxygen for treatment, and frequently for decompression, they have a large variety of protocols. Some use the UW O_2 for treatment, as prescribed. Others return to the depth of the dive (as deep as 30 m). Others routinely decompress on oxygen from variable depths, to avoid DCS. Re-education appears warranted.

PEARL DIVERS

This occupational group of about 100 divers off the North-West of Australia have had a horrendous diving history. Edwards[15,16] who writes on the history of these men, postulates that they have lost about 1,000 divers over the century of pearl diving.

The very optimistic and atypical "official" figures for 1993 claim no deaths and only 3 (later upgraded to 12) cases of DCS, all successfully treated by UW O_2, amongst the 74 divers in Broome. They conducted: 21,452 dives, about 15,000 hours underwater, averaging 290 dives per diver

The following information is pertinent:[16-18] They dive daily for 6-10 days, at the neap tides each month, for 5-6 months each year, 5-10 times per day, usually to depths varying from 15-45 m, but they do extend this range. The consecutive dives are as often deeper, as shallower. They usually use O_2 for decompression for some dives 13 m to 21 m and all dives over 23 m.

I carried out a survey by inspection of the diving logs (representing about 10% of the dives out of Broome and Darwin) over a 4 year period, 1988-1991, which is less reassuring. DCS was the commonest medical disorder recorded (45%). The existence of a DCS diagnosis in the diving logs was verified by the recorded extra O_2 decompression time. This involved a administration or extension of O_2 at 9 m for 30-45 minutes.

The incidence of DCS from a diving day increases progressively from: 0.2 % at 10-14 m depths to 13.6 % at 45-54 m depths.

Of the 1,834 diver days worked (11,776 dives), there were 56 cases of DCS. 1 required medevac. Fifty five were treated successfully on the U W O_2 regime.

By extrapolation to the remainder of the Broome and Darwin fleets, we can calculate a DCS case load of about 500 treated underwater on oxygen over those four seasons of diving.

Provisos must be noted.

1 All cases occurred at sea, and treatments were usually given within 30 minutes.

2 Irrespective of the symptomatology, the illness was always referred to as "a niggle". This, according to their regulations, permitted the diver to resume diving and thus not lose any days diving (and therefore money). Clinically, they were very obvious DCS cases.

3 Except for the diver who required medevac, most divers continued diving on that or the next day without any more problems (49/55).

4 We have no idea of how this treatment influences the propensity to dysbaric osteonecrosis.

Like the abalone divers, the pearl divers have modified the treatment regime, but not in the same manner. Their consistent routine is to employ oxygen for 30 minutes at 9 m, extendible if any symptoms persist, and then ascend at a relatively fast rate, 3 m per minute.

The rapid exposure to effective treatment may explain an apparent discrepancy, as in many of our delayed-treatment RCC cases, attempts to reduce the ascent rate from a very slow 12 minutes/m to 9 minutes/m, occasionally resulted in recurrence of symptoms.

As regards oxygen exposure, the 1988-91 pearl divers survey[20] disclosed a great deal of oxygen exposure, for both decompression and recompression therapy. Based on a 10% sample, there was a total of 10,064 days diving with oxygen. It averaged 70 minutes usage per day (range 10-150 minutes), spread over 1-5 dives with increasing durations and depending on the original dive profiles. There were no oxygen convulsions or toxicity's noted during this period. Nor have there been any since (personal communication, Dr Robert Wong, 1995).

Discussion

The physiological principles on which UW O_2 is based are well known and not contentious, although the indications for treatment may be.

It was originally hoped that the UW O_2 treatment would be sufficient for the management of minor cases of DCS and so avoid medevac requirements, and to prevent deterioration of the more severe cases while suitable transport was being arranged. When the regime is applied early, even in the serious cases, the transport was rarely required.

It is a common observation that improvement continues throughout the ascent, at 12 minutes per metre. Presumably the resolution of the bubble is usually more rapid at this ascent rate than its expansion due to Boyle's Law.

The UW O_2 recompression treatment is not applicable to all cases, especially when the patient is unable or unwilling to return to the underwater environment. It is presumably of less value in the cases where gross decompression staging has been omitted, or where a coagulopathy has developed. I would be reluctant to administer this regime where the patient has epileptic convulsions or is unconscious. Reference to the case reports in Annexe A reveals that others are less conservative.

One of the common reservations in Australia[19] is that this underwater treatment regime is applicable to the semi-tropical and tropical areas (where it was first used), but not to the southern parts of the continent, where water temperatures may be as low as 4°C. There are certain inconsistencies with this belief. Firstly, if the diver developed DCS while diving in these waters, then he is most likely to already have effective thermal protection available to him. Also, the duration for the UW O_2 treatment is not excessive, at a depth in which his wet suit is far more effective than at his original diving depth. If he is wearing a dry suit the argument is even less applicable. The most effective argument is that it is used, and often very successfully, in the cold southern waters of Australia.

Some claim that the UW O_2 treatment is of more value when there are no transport facilities available. Initially this was also our own teaching, but with the logic that comes with hindsight, only a 3 hour gap is needed between the instituting of UW O_2 therapy and the arrival of transport, to be able to utilise this system. It is probably more important to treat the serious cases early, even if full recovery is not achieved, than to allow the progression of pathology during those hours.

There is no doubt, especially in serious cases, that transport should be sought while the underwater treatment is being utilised.

There has been a concern that if this technique is available for treatment of DCS , other divers may misuse it to decompress on oxygen underwater, and perhaps run into subsequent problems. This is more an argument in favour of educating divers, than depriving them of potentially valuable treatment facilities. One could use this illogical argument to totally prohibit all safety equipment, including recompression chambers, and thereby hope to circumvent all diving related problems.

It has been claimed that UW O_2 treatment is unlikely to be of any value for those patients suffering from pulmonary barotrauma. It may well be so in some cases. The treatment was not proposed for this. It is, however, possible that the treatment may be of value for mediastinal emphysema, and perhaps even a small pneumothorax.

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 underwater treatment. Medevac's aggravate these difficulties and also introduce appreciable hazards of their own.

The UW O_2 treatment table is an application, and a modification, of current regimes. It is not meant to replace the formal treatment techniques of recompression therapy in chambers. It is an emergency procedure, able to be applied with equipment usually found in remote localities and is designed to reduce the many hazards associated with the conventional underwater air treatments.

The customary supportive and pharmacological adjuncts to the treatment of recompression sickness are in no way superseded, and the superiority of experienced personnel and comprehensive hyperbaric facilities is not being challenged. The UW O_2 regime, as described, is considered as a first aid regime, not superior to portable recompression chambers, but sometimes surprisingly effective and rarely, if ever, detrimental.

The relative value of current first aid regimes (the various UW O_2 procedures, including an additional deep air dip, and surface oxygen administration) needs to be clarified.

Whether we approve of the concept or not, it will continue to be used for as long as it is needed. The various diving communities are widening the UW O_2 protocol, and this may reflect the different types of cases encountered and the speed of its application.

Until we understand DCS better, the divers are more likely to research this field than medical experts, and they are unlikely to abide by our preconceived but well-intentioned restrictions.

The most effective way that I can envisage us contributing to diving medical first aid for DCS in remote areas, is by demonstrating a safer but equally effective UW or surface treatment e.g., with a helium/oxygen mixture that can be stored and used in emergencies, as oxygen is now.

ANNEXE A
CASE REPORTS

Because this treatment is often applied in remote localities, many cases are not well documented. Twenty five cases were well supervised before this technique increased suddenly in popularity. Two such cases are described.[12]

Case 1.

A 68 year old male salvage diver did two dives to 30 m (100 feet) for 20 minutes each with a surface interval of one and a half hours, while searching for the wreck of HMAS PANDORA about 100 miles from Thursday Island in the Torres Strait.

No decompression staging was possible, allegedly because of the increasing attentions of a tiger shark. A few minutes after surfacing, the diver developed paraesthesia, back pain, progressively increasing in coordination and paresis of the lower limbs.

Two attempts at underwater air recompression had been unsuccessful when the diving boat returned to its base moorings. The National Marine Operations Centre was finally contacted for assistance.

It was about 36 hours after the last dive, before the patient was finally flown to the regional hospital on Thursday Island. Both the Air Force and the Navy had been involved in the organisation, but because of very hazardous air and sea conditions, and very primitive air strip facilities, another 12 hours would have been required before the patient could have reached an established recompression centre 3,000 km (2,000 miles) away.

On examination at Thursday Island, the patient was unable to walk, having evidence of both cerebral and spinal involvement. He had marked ataxia, slow slurred speech, intention tremor, severe back pain, generalised weakness, difficulty in micturition, severe weakness of his lower limbs with impaired sensation, increased tendon reflexes and equivocal plantar responses.

An UW O_2 unit was available on Thursday Island for use by the pearl divers. The patient was immersed to 8 m depth (the maximum depth off the wharf). Two hours were allowed at that lesser depth and the patient was then decompressed. There was total remission of all symptoms and signs, except for small areas of hypoaesthesia on both legs.

Case 2.

A 23 year old female sports diver had been diving with a 2,000 litres (72 cu ft) scuba cylinder in the Solomon Islands. The nearest recompression chamber was 3,500 km. away and prompt air transport was unavailable. The dive was to 34 m (114 ft) for approximately 20 minutes, with 8 minutes decompression. Within 15 minutes of surfacing she developed 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. The involuntary extensor spasms recurred every 10 minutes or so.

The patient was transferred to the hospital, where neurological DCS was diagnosed, and she was given oxygen via a face mask for three hours without significant change. During that time an UW O_2 unit was prepared and the patient was accompanied to a depth of 9 m (30 feet) off the wharf. Within 15 minutes she was much improved, and after 1 hour she was asymptomatic. Decompression at 12 minutes per metre was uneventful and the patient was subsequently flown by commercial aircraft to Australia.

ANNEXE B
UNDERWATER OXYGEN CONVULSION
(Heron Is)

The only complication amongst “recreational” divers that I am aware of, is in a diver who sustained a tethering of his air line, followed by an emergency ascent, during which he may or may not have sustained pulmonary barotrauma, but which he definitely did inhale a considerable amount of salt water into his lungs.

Because of the rapid ascent and the fear of the development of DCS, he was given oxygen through a full face mask at a depth of 8 m. Within a few minutes he began to show clonic movements of his limbs and appeared to be losing consciousness. He was surfaced, and treated for his salt water aspiration, which cleared up over the next 24 hours. There were no sequelae but the provisional diagnosis of oxygen toxicity was made.

I find it difficult to understand how one can become toxic to oxygen, having sustained a salt water aspiration that produces an appreciable drop in arterial oxygen levels. It is not really known whether the problems were due to oxygen excess from the treatment or hypoxia from salt water aspiration. He did not have a typical epileptic fit.[13]

The actual events were clarified only after I attempted to follow up the case, and found that the movements were definitely clonic, the “unconsciousness” was only a possible impairment of consciousness and he was apparently cyanotic on the surface. Unfortunately the clinical data in this particular case is extremely unreliable, making differential diagnosis difficult. The heading of the article was misleading, to say the least.

ANNEXE C
ABALONE DIVER PROBLEMS WITH UNDER WATER OXYGEN BREATHING

There were a few cases of problems, usually associated with using oxygen in excess of 9 m depth, and often using it while continuing to catch abalone, thereby employing their oxygen decompression time in a more valuable manner. The cases were as follows:

Case 1

Breathing oxygen at 12 m caused his lips to "go funny" and he noted a tingling and numbness over the whole of his body.

Case 2

Used oxygen mainly because of his navy training and therefore his experience with this. The maximum depth and duration would be 1 hour at 15 m. He would continue collecting abalone during that time and sometimes noted his right arm twitching and jerking, a loss of sight, appearance of star light objects underwater, twitching of the mouth and body. He claimed never to have lost consciousness underwater, however other abalone divers state that this is not so and that he had been rescued at least once by his boatman.

Case 3

Lost consciousness after a few minutes (it must have been more than this as he had half filled his abalone bag) at about 18 m.

Case 4

Never used oxygen in excess of 18 m, and always tried to reduce the duration even at shallow depths, to less than 3 hours.

Case 5

After breathing oxygen for more than 10 minutes at 18 m, his eyes went swimmy and fuzzy and he started to twitch. These symptoms indicated to him that it was time to quit.

It can be seen by the above case reports that some basic training in the use of oxygen underwater was required and this was given during the 1985 Australian Abalone Diver Survey.

It is believed that, since that time, most of the abalone divers have been using the underwater oxygen, but not always as proposed in reference.[7] One was particularly worrying. The diver dives to 30 m regularly, and uses oxygen for both decompression and treatment from that depth. He frequently notices visual symptoms, such as "mini stick figures running around the edges of my vision". He will not alter this regime as he "feels better with it".

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Dr Carl Edmonds' address is Diving Medical Centre, 66 Pacific Highway, St Leonards, New South Wales 2065, Australia.

DIVING DOCTOR'S DIARY

DIVING DOCTOR'S DIARY

A TOUCH OF DECOMPRESSION SICKNESS

Carl Edmonds

Case report

A 42 year old male had a history of temporal lobe epilepsy between the ages of 10-15, adequately investigated by specialist neurologists at a major teaching hospital and with multiple EEG's. He was passed fit for diving by an inexperienced diving physician. The diver also happened to have hypertension and was taking beta blockers. The physician changed the beta blockers to a calcium channel blocker, ostensibly for safety's sake.

He completed a diving course satisfactorily and on his fourth dive after the course he did his first independent open water dive.

The dive was a single level one to 24 m and he was with an equally inexperienced buddy for 22 minutes before both of them, almost simultaneously, realised that they were very low on air. He could not actually remember the amount but it was "somewhere in the coloured section and it might have been 1 something or other". They decided to ascend fairly rapidly, through a bevy of bubbles. They omitted the 5 m stop on the grounds that they would have drowned had they stayed there. A reasonable decision under the circumstances.

The swim back to the boat was strenuous, against a strong current. Fortunately he was a fairly fit man.

After the dive there was no obvious problem until the following morning when he woke with a numbness and tingling "like a freeze burn", on the fourth finger of the right hand. By the end of that day it had spread to the other fingers and the following day it had spread to all the fingers of that hand. It was quite unpleasant and over the next few days proceeded to get worse, with significant paraesthesia and pain when pressure was applied to any of the fingers.

There was a possible history of a slight discolouration of the affected fingers, but this was not definite and did not persist.

By the time I saw him on the 6th day following the dive, there was a lessening of the symptoms, but they were also present on the left hand, on the third finger, to a minor degree. He was left handed and there was no past history of cervical spondylosis.

On examination there were no abnormalities on neurological testing.

Diagnosis and treatment

A decision had to be made regarding recompression therapy, even though he presented 6 days after the incident. What would you do?

I do not doubt that he deserved to get decompression sickness, but I do not believe he had it.

We decided against recompression therapy on the basis of the full history of the dive, which was not offered to any of the previous doctors who had assessed him. On specific interrogation, he readily admitted to the probable cause of the incident. During the dive, which was undertaken without gloves, he clutched at a large yellow/orange sponge in order to hold himself down (because of his inexperience there were some buoyancy problems) but it broke off in his hand. He also made a feeble attempt at grabbing it with his left hand as he floated up.

Therein lies the answer.

Final diagnosis, sponge injury.

Discussion

I am not sure of the likely response of this disorder to hyperbaric therapy, but my bet is that the cold decompression environment and/or the vasoconstriction of high pressure oxygen would probably reduce the symptoms, temporarily. He could then have been assessed as another case of resolving acute neurological decompression illness, successfully treated!

His symptoms had totally dissipated 2 days after the consultation. He has now decided to do a course on buoyancy control and to wear gloves.

Dr Carl Edmonds' address is Diving Medical Centre, 66 Pacific Highway, St Leonards, New South Wales 2065, Australia.

SPUMS NOTICES

S0UTH 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.

SPUMS ANNUAL SCIENTIFIC MEETING 1996

PARADISE ISLAND, THE MALDIVES
20th to 28th APRIL 1996

Theme
Technical Diving

The guest speakers will be Professor David Elliott (UK) and Dr Bill Hamilton PhD (USA). Professor Elliott's background is in naval and commercial diving and diving safety as well as co-authoring *The physiology and medicine of diving*. Dr Hamilton is a diving physiologist with special interest in decompression schedules. His advice has been sought, and taken, by many of the growing company of "technical divers" in the USA.

The conveners will be Drs Chris Acott and Dr Guy Williams. Intending speakers should contact Dr Williams at 8 Toorak Street, Tootgarook, Victoria 3941, Australia. Phone (059) 85 7161. Fax (059) 81 2213.

The official travel agents are
Allways Dive Expeditions, 168 High Street, Ashburton,Victoria 3147, Australia.

MINUTES OF THE 1995 ANNUAL GENERAL MEETING OF SPUMS

held on Castaway Island, Fiji on 27/5/95

Apologies

Drs John Williamson, Andrew Fielding, Malcolm Whaites, Graham McGeoch.

Present

All members attending the Annual Scientific Meeting.

Meeting opened 1550

1 Minutes of the previous AGM

The minutes of the 1994 AGM have been published (SPUMS J 1994; 24 (4): 199).

Motion that the minutes be taken as read and are an accurate record, proposed by Dr C Acott, seconded by Dr J Knight. Carried.

2 Matters arising from the minutes

None.

3 Annual reports

3.1 President's report (printed on this page)

4 Annual financial statement and Treasurer's report.

These are printed on pages 132 and 133

Motion that the financial statement and Treasurer's report be accepted, proposed by Dr C Acott, seconded by Dr J Knight. Carried.

5 Subscriptions fees for 1996

Motion that full members pay $90 and associate members $45, proposed Dr H Turnbull, seconded Dr M Davis. Carried.

6 Election of office bearers

Nominations had been received as follows:-

President	Dr Des Gorman
Secretary	Dr Cathy Meehan
Treasurer	Dr Sue Paton
Editor	Dr John Knight
Public Officer	Dr Guy Williams
Education Officer	Dr David Davies
Committee Members	Dr Chris Acott
	Dr Robyn Walker
	Dr John Willamson

There being no other nominations Dr G Leslie proposed that the above be declared elected. Seconded by Dr T Wong. Carried.

7 Appointment of the Auditor

Motion that Mr David Porter continue as auditor, proposed Dr J Knight, seconded Dr D Davies. Carried.

8 Matters of which notice had been given

None.

Meeting closed 1615

PRESIDENT'S REPORT 1995

It is with pleasure that I make my fifth report as the President of our Society, and in particular it is very pleasing that this report is given to a Society that is healthy and at an AGM that has set a clear benchmark for attendance and activity. Congratulations are due in this context to the convener and guest speaker, Drs David Davies and Fred Bove respectively, to both Geoff Skinner and Adrienne McKeonne, and to the managers and staff of Castaway Island Resort and the diving operators. Clearly, the message is, "get the right venue, theme and guest speaker and the Society will give its full support". To all of you here, thank you for your attendance and interest.

As a Society we have had some major gains in the last year, not the least the change in public stance of the AMA with respect to the need for medical practitioners to be trained in diving medicine to be able to undertake assessments of diving fitness. Equally important, in my opinion, the meeting in Cairns that was sponsored by the Queensland Government heralds a new period of co-operation between the Society and the recreational diving community. Again, I am delighted to see an active role being taken in the Society by those members who are representatives of that community. One of the this year's tasks for the Executive is to revise the criteria for full membership of the Society so that this role can be expanded. No doubt this will aggravate the "flat-earthers", but so be it.

Any Society of our size will generate dissent and ours is typical in this regard. However, I am disappointed by the standard of some of the correspondence that has been published in the Journal. This is no reflection on our Editor; indeed, it has been our policy to ensure that all opinions are given "their moment in the sun". Unfortunately, we must review this stance in the context of recent letters to the Editor that have been essentially defamatory. Indeed, I believe that any letter that is critical of anyone else or an external agency or facility should not be published unless the people criticised have had the opportunity to read the correspondence and to prepare a reply to appear in the same issue of the Journal. Recourse to legal opinion about the risk that a letter represents to the Society if it is published may be necessary.

While on the subject of the Journal, it would be remiss of me not to reiterate the Society's appreciation to our Editor, Dr John Knight. The Journal continues to bring great credit to the Society and, by itself, remains our prime recruiting tool. It is stating the obvious to argue that an Assistant-Editor is needed, to both help John and to establish a succession. If anyone wishes to volunteer for this task, or better still to volunteer someone else, then please get hold of one of the Executive before we leave Fiji.

Similarly, I have no difficulty in sincerely thanking the members of the Society's Executive Committee, and in particular our secretary and treasurer, Drs Cathy Meehan and Sue Paton. It is important that "new blood" continue to infiltrate the Executive and this has occurred in recent years to the benefit of the Society.

What of the future ? Next year we return to the Maldives and to an exciting new destination. Allways Tours will be the conference organisers, and Drs Guy Williams and Chris Acott will convene the meeting. The conference will be dedicated to a workshop on technical recreational diving, and I am delighted to report to you that both Dr Bill Hamilton and Professor David Elliott have agreed to be our guests. Chris Acott has accepted the challenge of making the workshop a joint venture with the European Undersea Biomedical Society. Certainly the subject matter will guarantee an active debate. I see that some of the protagonists of such diving have written to our Editor questioning our ability and role in such a debate. To such people, I would suggest that "they turn up and put up, or shut up". If they are unable to afford to attend, having just bought a "rebreather", then provide a written submission. The workshop's integrity is ensured by the calibre of our guests and I have no doubt that it will be a great success. For those who are more interested in the non-academic activities, the timing of next year's meeting will hopefully reduce the risk of the poor weather that spoiled the diving on our last trip to the Maldives.

As some of you are aware, I leave full-time service with the Navy this year to establish an Occupational Medicine Department at Auckland University. In addition to a title that almost fits my ego, this is a challenge that I am looking forward to; although I have no illusions about the work involved. In this context, I am examining my commitments in general. This includes my role in this Society and I am fully aware that next year in the Maldives I will have been President for 6 years. I am not sure that this is necessarily healthy for any Society and during the year I intend to canvass possible replacements. Again, if you wish to volunteer yourself or someone else, please come and see me before we leave Fiji.

Again, thank you for your attendance and support and I look forward to seeing you all in the Maldives.

Des Gorman,
President.

TREASURER'S REPORT

Membership statistics

The total membership of SPUMS was 1,190 in April 1995 (Australia 871, New Zealand 117, North America 115 and other 87). This number oscillates by 50 or so during the year with new memberships (over 100 annually) and attritions.

About one third of Australasian members had not paid this year's subscription by April and had to be billed again.

The "Diving Doctors" list currently (May 1995) has a total of 363. There are anywhere between 50 to 100 changes made to this list every quarter to keep it as accurate as possible.

Financial position

I am pleased to be able to report that the Society's finances remained sound at the end of our last financial year in December 1994 .However we our recurring expenses have increased. In 1994 we bought two facsimile machines and new computer software. In 1995 we intend to upgrade the Treasurer's computer and provide the Secretary with a compatible system. The Editor's honorarium started in July 1994, so in the last financial year we paid only $4,272. This year we will have to find the full $ 12,000. Costs of secretarial assistance for Dr Meehan and myself rosee in 1994 and are running at a higher rate this year. All these represent an extra $10,000 in recurring expenses even without allowing for likely rises in the of printing and other services which should be anticipated with CPI increases.

From the statement of accounts for the year ended 31st December 1994 there is an apparent substantial rise in income, however, this will not be a continuing rise each year because;

1 in 1993 many members had already paid for 18 months in July 1992 making 1993 subscriptions unusually low,
2 sponsorship was gratefully received from Submersible Systems,
3 owing to the late inability to attend of our guest speaker in Rabaul, part of the funds allocated for his costs from the registration fees were reimbursed to the Society. With the addition of the refund of deposit from CIG PNG for oxygen cylinders on dive boats these funds were used top pay for the two pulse oximeters which SPUMS donated to the local hospital.

The balance of $570 only partially covered the costs of printing the agenda for the Scientific Meeting and the conference booklet which was sent out with the September 1994 issue of the Journal. These costs are shown separately as AGM costs in Expenditure. In future these will be covered by the Conference registration fee which is now collected directly by SPUMS.

Subscriptions

Prudent financial management dictates that the Society's present level of reserves be maintained and that increases in routine expenditure be covered by subscription income. We can only raise subscriptions at an AGM and so if we do not act now we cannot raise subscriptions until the 1997 financial year!

So I am proposing, with the Committee's unanimous approval, that the subscriptions for 1996 be $90 for full members and $45 for associates. With a total membership in April 1995 of 1,190 (880 members and 310 associates), these increases will be enough to cover adequately our expected increases in expenditure.

Sue Paton
Treasurer.

SOUTH PACIFIC UNDERWATER MEDICINE SOCIETY
STATEMENT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 31ST DECEMBER 1994

		Year ended 31/12/94		Year ended 31/12/93	
Opening balances					
ANZ Bank	Access account	945		6,131	
	Cash Management account	-		1,017	
	ANZ V2 PLUS	42,499		37,107	
			43,444		44,255
Income					
Subscriptions		80,963		32,626	
Interest		2,279		2,036	
Advertising and Journal sales		1,250		2,506	
Sponsorship		2,585		5,000	
Reimbursement of Registration (PNG)		6,932		-	
Refund from CIG (PNG)		1,138		-	
			95,147		42,168
			$138,591		**$86,423**
Expenditure					
AGM costs		1,417		-	
Donation of 2 oximeters (PNG)		7,500		-	
Secretarial		5,142		1,451	
Stationery and printing		3,012		709	
Journal		23,442		19,428	
Postage and facsimile		5,638		3,131	
Conferences and telephone		10,487		7,817	
Equipment (see note)		6,905		5,913	
Miscellaneous and subscriptions		1,394		473	
Bank charges		1,343		710	
Audit		350		350	
North American Chapter costs		0		2,997	
Editor's honorarium		4,272		-	
			70,902		42,979
Closing balances					
ANZ Bank	Access account	(364)		945	
	ANZ V2 PLUS	68,053		42,499	
			67,689		43,444
			$138,591		**$86,423**

Notes
1 Equipment is written off as purchased.
2 Subscriptions are on a receipts basis.

These are the accounts referred to in the report of D S Porter, Chartered Accountant, Newport Beach, New South Wales, Australia.

Auditor's report

I have conducted various tests and checks as I believe are necessary considering the size and nature of the Society and having so examined the books and records of the South Pacific Underwater Medicine Society for the year ended 31st December 1994. I report that the accompanying Statement of Receipts and Payments has been properly drawn up for the records of the Society and gives a true and fair view of the financial activities for the period then ended.

12th May 1995 David S Porter, FCA, Chartered Accountant

THE NEW ZEALAND CHAPTER PAGE

SPUMS NEW ZEALAND CHAPTER ANNUAL SCIENTIFIC MEETING

Mike Davis

Neither a torrential storm that had Tairua cut off from the rest of New Zealand nor the non-arrival of one, the withdrawal of another and the late arrival of a third of the main speakers spoiled a lively gathering of 25 SPUMS members in early April.

Although as a result the original goals of the meeting, to reach consensus statements on fitness for diving and asthma and diving to take to the main meeting in Fiji, could not be achieved, nevertheless some lively debate on these topics ensued. It was quite clear that few if any members support a purely prescriptive approach toward the assessment of the health risks of candidate sport divers. At the same time it was recognised that there is a dearth of useful epidemiological data, and that SPUMS must take the initiative in developing studies to clarify some of these issues. One such study has commenced in Auckland.

The view of the training agencies was “why fix something that isn’t broken” and that there would be a very low or non-existent number of diving deaths or accidents in New Zealand that could be avoided by altering the existing arrangements in this country for diving medicals. This is an arguable statement, but born out by their current incident monitoring program. No clear view as to the ideal system for medical screening of sport divers was achieved. The Chairman drew parallels with assessment of fitness for anaesthesia, where increasing reliance is being placed on well designed questionnaires for initial screening, followed, only where indicated, by medical assessment by a specialist anaesthetist

Amongst some of the issues raised during the debate were the importance of impressing on sport divers that primary responsibility for their health and safety lay with themselves, the potential medico-legal problems that a discretionary system might carry with it and the importance of improved liaison and relations between “diving doctors” and the training organisations, since in the past this has not always been of the best. The presence of representatives of New Zealand Underwater, PADI and SSI, all of whom took an active part in discussions was certainly a positive contribution to the latter.

With regard to asthma, the Chairman presented a series of his own and a colleague’s cases in which a black-and-white approach to those with a history of asthma was not adopted but each case was assessed on its own merits. By proxy, Dr Veale presented figures showing that on present epidemiological information it was completely impossible to demonstrate whether or not asthmatics were at greater risk than non-asthmatics during scuba diving. All at the meeting agreed that there were many asthmatics diving, but what proportion of the diving population they represent was unknown.

Other presentations

DEPARTMENT OF LABOUR DIVING MEDICAL DIRECTORATE
Des Gorman

The Auckland Diving and Hyperbaric Medicine Group has been operating the Department of Labour Diving Medical Directorate (DMD) since 1990. The DMD acts as an arbiter and maintains a central database. Medical records are forwarded to examining and treating medical practitioners on request and given consent. The nature of the annual examination of occupational divers is under active review. The compulsory chest X-ray has been abandoned and the need for annual spirometry is now being questioned. In this context, the rate of any reform is slowed by the need to maintain international reciprocity. A new medical history questionnaire is being developed.

DIVING CASES AT THE SLARK HYPERBARIC UNIT (RNZN HOSPITAL) JANUARY TO MARCH 1995
Simon Mitchell

Forty two cases of decompression illness (DCI) were treated at the Slark Hyperbaric Unit during January to March 1995. All cases were sport divers. Eighty percent were diving within the limits imposed by their own tables or computers, however in only 36% were the dives within the limits of the DCIEM tables. Half the divers had neurological involvement. A full recovery by discharge occurred in 85%.

Case Report

A 27 year old male performed a single 30 m dive for 15 minutes with a normal ascent. Within five minutes of surfacing, he noticed low back pain similar to previous episodes unrelated to diving. For 15 minutes he also felt dyspnoeic, tingly and light-headed. He was evacuated to the unit where he had residual back pain and was neurologically normal on examination. Voluntary hyperventilation reproduced the sensations of dyspnoea, tingling and light-headedness, and the diagnosis of DCI was considered unlikely. Nevertheless, within six hours of the dive, he received a USN Table 6 as a precaution. The back pain was unaltered by this.

On waking the following morning, he had bilateral leg weakness, bladder dystonia, and was unable to walk. A further compression to 2.8 bar produced no improvement in these symptoms. In view of the possibility of surgical disease unrelated to diving, he was transferred for neurological assessment and MRI scanning. The MRI scan showed no abnormality. It was decided that DCI was the only rational diagnosis, and further treatment with a 50 m table produced definite improvement. He underwent a further 12 daily HBO treatments which produced almost complete recovery.

This case was notable for the development of dramatic spinal symptoms after a definitive hyperbaric treatment, the negative finding on MRI despite his previous history, and the apparent advantage of the deeper compression.

INVESTIGATION OF THE ROLE OF LIGNOCAINE IN BRAIN PROTECTION IN EMBOLIC BRAIN INJURY

Simon Mitchell

(work in progress toward a doctoral thesis)

Lignocaine in conventional anti-arrhythmic doses has been demonstrated to preserve somatosensory evoked responses in animal models of air embolism, focal and global ischaemia. Several studies have demonstrated reduction of ischaemic neuronal damage by lignocaine. Cerebral protection by lignocaine may be related to one or more relevant properties. Lignocaine is able to decelerate ischaemic ion fluxes in neural tissue, reduce cerebral metabolic rate, reduce migration and superoxide elaboration of leucocytes, and exerts several potentially beneficial haemodynamic effects.

Cerebral protection by lignocaine is under investigation in cardiac surgery patients at Green Lane Hospital, Auckland.

Cardiac surgery is associated with neurological sequelae that are linked to embolic events, particularly where cardiotomy is performed. Consenting valve replacement patients at Green Lane Hospital undergo an extensive battery of pre-operative neurocognitive tests. At surgery, patients receive a double blinded infusion of either lignocaine in conventional anti-arrhythmic doses, or saline. The infusion is continued for 48 hours. The peri-operative passage of emboli through the right carotid artery is monitored and quantified using a colour flow Doppler machine interfaced to a purpose-built signal processor. The neurocognitive tests are repeated at 8 days, 8 weeks and 6 months post-operatively. The changes from the normalised baseline for the various tests will be compared between the lignocaine and saline groups. To date, 15 patients have entered the protocol. The results of this study will have some bearing on the issue of lignocaine's role in the treatment of DCI.

An unexpected incidental finding arising from the Doppler monitoring is the observation that combined venous/cardiotomy blood reservoir volumes at the lower end of the commonly utilised range result in significantly higher numbers of emboli reaching the patient during established bypass. The suspicion that these reservoirs actively self generate bubbles at low volumes has been confirmed in vitro. Bypass practice at Green Lane Hospital has been altered in response to this finding.

Officers of the New Zealand Chapter, 1995-96

Chairman

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Secretary/Treasurer

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Past Chairman

Dr Andy Veale, Green Lane Hospital, Green Lane West, Auckland 3, New Zealand. Telephone (work) 09-631 0754, (home) 09-524 4291, Fax 09-623 1172.

MINUTES OF THE ANNUAL GENERAL MEETING OF THE NEW ZEALAND CHAPTER OF SPUMS

held in The Shell Room, Pacific Harbour Motel, Tairua, New Zealand, on 8 April 1995

The Meeting opened at 0930.

Present

Chairman and 20 members.

Apologies

Rhys Jones, Graham McGeoch, Chris Strack. Accepted: Bennett/Sutherland

Observers

Colin Melrose (PADI), Morgens Poppe, Ben Castle.

1 Minutes of the last AGM

Accepted, carried Pemberton/Wakely

2 Matters arising from minutes
None raised.

3 Chairman's report

Apart from the organisation for this year's meeting there have been no activities to report.

4 Secretary/Treasurer's report

Since there was no expenditure during the current year, only the current status of the bank accounts was tabled. There was no secretarial business.

5 Nominations for office bearers of the New Zealand Chapter of SPUMS 1995-6

5.1 Chairperson: Dr Mike Davis, Christchurch. Nominated Bennett/Stephens. Carried
5.2 Secretary/Treasurer: Dr Chris Morgan, Rotorua. Nominated Davis/Jones. Carried

6 Possible venues for future meetings.

Mike Davis suggested that Christchurch was an option in 1996 to coincide with a formal re-opening of the Hyperbaric Chamber based at the Public Hospital which was likely to be funded (after protracted negotiations with, and prevarication by CHE and RHA bureaucrats) and this might be held back-to-back with a Fiordland venture. Paul Wakely suggested that Tairua had proved to be a popular venue and although diving had not been possible because of the atrocious weather conditions this time, it would be nice to try again next year. Philip Baker suggested that Tutukaka was also worth considering. A decision would be taken as soon as the future of the Christchurch chamber was known.

7 The future of the New Zealand Chapter of SPUMS

Discussion of a report by Dr Andy Veale (printed as appendix).

The following points were raised:

7.1 Des Gorman stated that it is not possible to have a separate constitution for the New Zealand Chapter of SPUMS. The Society is incorporated in Victoria.

7.2 CME Credits. Alan Sutherland suggested that annual scientific meetings at HMNZS PHILOMEL would be credited as CME points.

7.3 Rex Gilbert (NZU) will produce the latest information in accident statistics and forward these for the newsletter. Rex has already brought the NZU reports more in line with DIMS (Diver Incident Monitoring Survey which based on the Hyperbaric Unit in Adelaide) and is in regular touch with Adelaide. Mike Davis will contact Chris Acott requesting DIMS forms.

7.4 Des Gorman mentioned that an abstracting system for articles exists within the Navy Base, and that this could be made more widely available to members. It was agreed that a new edition of Bennett & Elliott be purchased through Chapter funds to be held at the Navy Hospital.

7.5 It was not felt appropriate to have a separate newsletter, but that a regular NZ column should appear in the SPUMS Journal.

8 Financial Report

There is nearly $6,000 in two accounts. This money has been virtually untouched for several years. Mike Davis suggested that the money be used for airfares and accommodation of visiting speakers. The money should be used for education of the New Zealand Chapter of SPUMS members. To this end, Des Gorman suggested that David Elliott be re-routed from the April SPUMS meeting in the Maldives. This was agreed to. Gorman and Davis to approach Elliott.

Those present at the meeting agreed that the Chairman and Secretary/Treasurer look at rationalisation of the accounts. Alan Sutherland reminded members that the Founders' Fund was set up expressly for educational purposes.

9 General Business

9.1 Quentin Bennett commented that it was very difficult to join the New Zealand Chapter of SPUMS. Mike reminded members that the completed forms should be sent directly to Australia. He welcomed two intending members: Drs Morgens Poppe from Tairua and Ben Castle from Rotorua.

9.2 Notices inviting new members will be placed by the Secretary in the following journals: NZGP, NZ Doctor, Dive Log and NZ Sports Medicine.

9.3 Des Gorman mentioned that fees may increase to A$100. An active discussion followed this. There are just over 1,100 financial members in all, with 807 in Australia and 104 in New Zealand. He mentioned that the SPUMS Journal Editor is receiving a stipend and that there is discussion about paying the Secretary. The Society is solvent but efforts must be made to keep it that way.

9.4 Alan Sutherland suggested that a certificate of attendance be provided for purposes of points toward CME credits. This received widespread affirmation. The question of CME recognition will require further exploration.

10 Other Business

Mike Davis thanked the conference organisers, Christopher and Jocelyn Morgan and Martin Rees and all who attended the meeting.

The meeting closed at 1115.

APPENDIX TO THE MINUTES OF THE 1995 AGM OF THE NEW ZEALAND CHAPTER OF SPUMS

THE FUTURE OF THE NEW ZEALAND CHAPTER OF SPUMS, ANDY VEALE (PAST CHAIRMAN, NZ CHAPTER) A DISCUSSION DOCUMENT FOR 1995 AGM

(Edited by Mike Davis)

Clearly we operate under the umbrella of the overall SPUMS organisation and abide by their aims, objectives, rules and finances (copy enclosed).

Chapter aims and objectives

I believe that the local branch should have specific aims and objectives also. These I would see as being:

1 To organise and run an Annual Scientific Meeting.

2 To provide access to diving in a collegial environment, with colleagues, allowing the development of advice networks. Obviously, this is currently undertaken with the annual Scientific Meeting. There are however some conflicting requirements between a scientific meeting and a good diving site.

3 To keep New Zealand members informed about local New Zealand matters, particularly those relating to morbidity and mortality. Data collection was initially

performed by an accident recorder from within NZUA who, coincidentally, was also a doctor member of SPUMS. This has subsequently been provided by Rex Gilbert, an experienced NZUA instructor, and more recently still, by NZU in conjunction with the Diving and Hyperbaric Medical Unit at the RNZN.

4 To provide members of SPUMS with access to library resources and material.

5 To provide a list of speakers available to speak to local postgraduate societies.

In order to facilitate these aims, I believe we need to develop a written constitution and structure for the local group, or a constitution and structure could be developed by the parent SPUMS organisation to apply to branches. This needs to be specific and all inclusive, outlining the relative responsibilities of the local organisation, and of the parent organisation, particularly as to the disbursement of funds.

Officers of the Chapter

The officers of the New Zealand Chapter of SPUMS should be Chairman, Secretary/ Treasurer and Scientific Meeting organiser. I am not certain of the need for the Past Chairman. Formal written nominations should be sought from the entire membership 3 months before the AGM and a postal ballot undertaken so the office holders are known at the time of the AGM.

Newsletter

We should develop a newsletter to NZ SPUMS members, or perhaps to be published as a NZ page in the SPUMS journal. This should have a structured format.

a NZ Water Safety Council reported deaths. This appears to give the most reliable information on both scuba and free diving deaths.

b ARCIC (the ACC for short) reported incidents. It is not yet clear what degree of injury will be necessary to be recorded in the database, but there is considerable interest in developing comparative data for sports injury. The databases will be accessible to bona fide researchers in a structured format.

c NZU / RNZN Unit accident recorder incident data.

d Chamber statistics. This should include non-diving related hyperbaric therapies and a description of new research proposals. Research in progress could be reported in brief annually.

e Issues of medical relevance, case reports with teaching message, etc.

f Letters. If in the Journal, this could be omitted as there is a vibrant Letters to the Editor section.

Annual Scientific Meeting.

The annual meeting site should be decided two years in advance with an appointed organiser. I believe that the scientific content should take precedence over diving in regard to the suitability of site. Notification and advertising should include non-SPUMS members (through NZ Doctor, NZ General Practitioner and NZMJ) and probably also to non-doctors (via NZU, NAUI, PADI, Commercial Divers organisation, etc.) to allow wider dissemination of medically oriented information in the general diving community and among those performing diving assessments. There should be a financial float from the parent organisation to initiate the meeting but the meeting should run at a small profit.

I feel that discussion of case reports should be undertaken on every trip to dive sites, only in this way can we learn from others, and learn the uncertainties relating to every case. Good clinical judgement comes from experience, but remember experience comes from bad clinical judgement. Reports as outlined above should be incorporated.

SPUMS Chapter Library

The SPUMS (NZ) library should continue to be administered and cared for by the RNZN hospital, but there should be a regular (at least annual) notification to all SPUMS members of the title list and that surplus monies from the annual scientific meeting should go to the provision of additional books. The scientific meeting could be organised to provide about $200-$500 profit or alternatively and I believe preferably, a small supplement to the subscription could provide for this.

SPUMS Diving Medical Sub-committee

I do not think that the President/Secretary/Treasurer need necessarily be of scientific bent, or even interested in the minutiae of diving medicine. Hence the Executive of the New Zealand Chapter of SPUMS in any year cannot be considered "expert" from the point of view of liaison with governmental organisations. Either this important advisory role needs to be provided by the RNZN Diving and Hyperbaric Medical Unit as at present, or alternatively a scientific subcommittee should be established to provide this advice, in order to remain credible.

SPUMS ANNUAL SCIENTIFIC MEETING 1994

THE PROBLEMS IN THE MODELLING OF INERT GAS KINETICS

Des Gorman

Abstract

The models used to describe the kinetics of inert gases during underwater diving are inadequate. Medical practitioners and scientists interested in such diving have attempted to quantitatively describe the behaviour of nitrogen in compressed air diving since 1908, with little success. The problems encountered during this diving research are relevant to anaesthesia theory and practice.

Introduction

Although inert gas kinetics become complex if bubbles form, the "inertness" of these gases should make their uptake, distribution and elimination simpler to model than gases and drugs which are metabolised. The history of these inert gas models however is that they describe events poorly. Indeed, the limited success of decompression schedules (since the first was introduced in 1908)[1] in diving, caisson work and aviation is relevant to anaesthesia theorists because it demonstrates the unsatisfactory nature of available models of inert gas kinetics. Given this recorded history of diving research and the perfusion-solubility bias of current theories of anaesthesia gas, vapour and drug kinetics, it is difficult to escape the conclusion that there has been little "cross-fertilisation" of ideas between the two disciplines to date.

A review of inert gas kinetic models is consequently presented here to demonstrate the lessons available (problems encountered) to anaesthesia from diving research. This will take the form of discussing these kinetics in the context of a compressed air dive to 30 metres of seawater (msw) depth. A similar, or identical. discussion would have resulted if a caisson worker or space-walking astronaut or patients receiving N_2O anaesthesia had been considered.

The requirement of an inert gas model

The objective of an inert gas model in diving is to develop a decompression program that will prevent decompression illness. This will require the following to be defined and then modelled:

a the factors that influence the uptake of the inert gas into tissues during the dive (relevant to anaesthesia);

b the factors that influence the elimination of the inert gas from tissues during and after the dive (relevant to anaesthesia); and

c the conditions that must exist before bubbles form, as a limit to, or controller of the decompression (not usually relevant to anaesthesia).

Uptake of inert gases in an air dive to 30 msw

As the diver swims down or is lowered to 30 msw (400 kPa or 3040 mm Hg) breathing compressed air, the inspired nitrogen tension (PiN_2) will increase as predicted by Dalton[2] (Equation 1).

$$\begin{aligned} P_iN_2 &= P_{amb}.F_iN_2 \\ &= 400\ kPa.0.8 \\ &= 320\ kPa \end{aligned} \qquad \text{Eq.1}$$

where P_{amb} is the ambient pressure and F_iN_2 is the inspired nitrogen fraction. All published models assume that the alveolar (PAN_2) and arterial (PaN_2) nitrogen tension will also be at 320 kPa. The intrinsic assumptions here therefore include that respiration is not rate-limiting and that there is no significant venous admixture to arterial blood. However, following the withdrawal of an anaesthetic gas or during and after a decompression, inspired gas tensions will vary from alveolar and arterial tensions. Also at great depth, respiration and gas diffusion will be limited by gas density.[2] Nevertheless, the presumption that inspired, alveolar and arterial gas tensions are approximately equal is generally true and constitutes a small "error" in comparison to others described below.

The rate at which any given tissue will achieve a nitrogen tension (P_tN_2) in equilibrium with PaN_2 (320 kPa) will be determined variously by:

a the tissue perfusion;

b the relative solubility of N_2 in blood and in the tissue;

c the diffusion of N_2 into the extra- and intracellular fluid of the tissue; and

d the local tissue temperature, carbon dioxide tensions and work (which will influence perfusion, solubility and diffusion).

No model currently exists to account for all these factors and their potential interactions.

The majority of models, back to 1908, assume that uptake is determined only by tissue perfusion and relative solubility.[3] A single function exponential is used to calculate the P_tN_2 at a specific time (T) (Equation 2).

Eq.2.

where 80 kPa is the P_tN_2 on leaving the surface, 320 kPa is the PaN_2 on reaching 30 msw, Q is the blood supply to the tissue, and $\alpha\beta$ and αt are the solubility of N_2 in the blood and tissue respectively. Obviously, for a specific tissue, a fixed half-life $T_{1/2}$ can be ascribed.

The strength of this model is its simplicity. The major weakness is that the rate of actual uptake of N_2 into tissues has little in common with that predicted by the model.[4] In part, this failure is not surprising given the inherent ignorance of diffusion in the model[5] and the observation that most tissues have intermittent local perfusion.[6] It is clear that any uptake calculated from Equation 2 is based on the assumption of "instantaneous" diffusion of gases throughout the tissues (i.e. within a "circulation-time") and of continuous blood flow. Such an assumption may only be appropriate for small non-polar gases and for well perfused tissues such as the brain.

The only other significant alternative has been that proposed and used by the British researchers, Hempleman[3] and Hills.[5] Their argument is that gas uptake is reasonably described by considering diffusion alone (ie. a bulk-diffusion model based on the PaN_2 and the square root of time). There are no data to support either this theory (which arose from an empirical observation that a bulk diffusion model resulted in a reasonable prediction of the decompression programs employed by the United States Navy) or the consequent decompression schedules. Again, reality is poorly described (quantitatively) by these "diffusion" models. This is not surprising given the obvious limits on gas uptake that arise from perfusion and solubility and the observation that the United States Navy decompression programs studied by Hempleman[3] and Hills[5] often result in decompression illness.

Why is there no comprehensive model that considers relevant perfusions, solubilities and diffusion? The likely explanation is that the resultant model is difficult to manage. Also, some of these factors are reasonably unpredictable (local perfusion), unmeasurable (diffusion coefficients for gases in intracellular fluid) and inter-related (eg. an increase in temperature will increase some tissue perfusion, reduce the solubility of the gas in the tissues and simultaneously increase the rate of gas diffusion, such that an increase in tissue temperature may increase the uptake of an insoluble gas like helium and conversely decrease the uptake of a soluble gas like nitrogen).

Thus, while the phenomena that influence gas uptake are reasonably identified, 85 years of modelling has not resulted in an accurate quantitative description.

Elimination of inert gases during and after an air dive to 30 msw

A return to the surface will cause the P_iN_2 to return to 80 kPa and a consequent decrease in PAN_2 and PaN_2. Nitrogen will exit tissues until the P_tN_2 is restored to 80 kPa. Again, tissue perfusion, gas solubility, gas diffusion, tissue temperature, tissue carbon dioxide tensions and local tissue work will influence this elimination. Almost all models used and in use describe inert gas elimination as a mirror image of uptake. This gives an even worse "fit" than the determination of uptake as, for reasons that are not yet understood, inert gas elimination is much slower than uptake.[7] One or two models have tried to allow for this by deriving elimination kinetics as a 1.5 times slower function of uptake.[3,7] Unfortunately, this is a gross underestimate. For example, it takes several days to mass-balance the N_2O excreted after a brief exposure to this gas.[8]

It is possible that no gas is inert and that they all variously become "involved" in biological processes. In contrast, theorists have assumed that inert gases "passively" enter solution in tissues in proportion to the tissue gas tensions as estimated by Henry's Law.[2]

Inert gas elimination from tissues into blood becomes even slower still if bubbles form as much of the tissue gas will diffuse into the bubbles.[3,9,10] This is a fundamental observation; but, despite its critical relevance to repeated diving exposures and the development of decompression illness, is not incorporated in any existing model (presumably because the necessary mathematical model is extraordinarily complex[11]).

The formation of bubbles

Assuming that some estimate of gas uptake and elimination can be achieved, decompression can only proceed adequately if bubble formation is avoided. What then, are the conditions for bubbles to form? Using a Gibbs Free Energy construction,[12] the bubble energy (E_B) required for a spherical bubble to form in a compartment is equal to the sum of the energy needed to overcome surface tension ($E\gamma$) and for gas to come out of solution (E_{SOL})(Equation 3).

Eq.3.

where r is the radius of a spherical bubble and γ is the surface tension of the tissue liquid. Even if values of surface tension measured in lung surfactants (eg. 8 dynes/cm) and not in plasma (eg. 45 dynes/cm) are used, the Eγ needed for a bubble to form would require a relative decompression of about 1000:1. Instead, a decompression of only 1.4:1 can be shown to cause bubbles in divers.[3] There is then a gross inequity between theory (models) and observation. Although this disparity might be explained by the effect of tribonucleation and shearing of tissue places (to create relative vacuums), surface defects in tissues and vessels (where the surface tension pressure acting on the "forming" bubble will be minimised) and the ongoing formation of bubble nuclei (these may only exist for picoseconds but will reduce the energy required for stable bubble formation by acting as "seeds");[13] again, theory (models) and quantitative reality are at variance.

Finally, the relationship between P_tN_2 and P_{amb} (the final component of Equation 3) that will cause a nitrogen based bubble to form has been debated without consensus since 1908. This relationship has been described as everything from a constant ratio,[1] to a variable ratio,[3] to a constant difference[3] and to a variable difference.[14] This uncertainty continues because the time of initial bubble formation can not be precisely determined, by either the time of development of symptoms (known to occur after mobile bubbles can be identified in the veins)[15] the ultrasonic detection of mobile venous bubbles ("known" to occur after stationary bubbles form in tissues). Emergent acoustic techniques may help to resolve this dilemma. Overall, it is likely that N_2 based bubbles will form whenever PtN_2 exceeds Pamb.

Nevertheless, even assuming that acoustics will solve this problem, the modern theorist will still be faced with an old riddle, the intrinsic desaturation of tissue and venous blood relative to P_{amb} that results from the conversion of less soluble oxygen to more soluble carbon dioxide, and the effect that this desaturation will have on gas kinetics and bubble formation.[13] In anaesthesia, the breathing of higher than "normal" oxygen fractions will increase this degree of desaturation.

Since the first observation of decompression illness suddenly developing in a diver during a decompression stage (i.e. not actually undergoing decompression at the time) when the breathing gas was changed,[16] it has also been argued that changing the breathing gas may induce bubbling if the gases have widely differing diffusion coefficients. This has now been refined to differing net flux rates (where gas flux is a product of both gas diffusion and solubility). Observations in vivo suggest that changing from air to rapidly fluxing gases such as N_2O (and oxygen) will expand existing bubbles, but will not, fortunately for existing anaesthesia practice, provoke de-novo stable bubble formation.[17,18] Nevertheless, theoretically and anecdotally,[19] N_2O should not be administered to someone who has been compressed air diving within the last month as it may precipitate decompression illness (by causing pre-existing bubbles to grow).

Conclusions and recommendations

Clearly, there is a need for a comprehensive model of inert gas kinetics. In the interim, two practical recommendations can be made. Firstly, the choice of a decompression schedule for diving (ie. a method of practice) should be based on the demonstrated performance of that schedule and not on the attraction of the underlying inert gas model. Secondly, the real need at present is not for the production of more simplistic models of such inert gas kinetics, but rather for an accumulation of objective data to enable eventual definitive modelling.

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Key Words
Anaesthesia gases, Gas uptake, Gas elimination, Bubble formation, Decompression illness

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THE RETRIEVAL OF DIVING INJURIES IN NEW SOUTH WALES A RETROSPECTIVE REVIEW OF TWO YEARS PRACTICE

Mike Bennett

Abstract

The only medical recompression facilities available in NSW in case of decompression illness (DCI) are located in Sydney. Many cases must travel considerable distance to reach definitive treatment. A sophisticated network of retrieval facilities exists in NSW using road, fixed wing and helicopter transport platforms. Criticism has been generated over the use of helicopters for this purpose both with respect to altitude stress and vibration characteristics. While the issue of vibration as a possible deleterious influence on outcome seems to have settled somewhat with the advent of the twin engine machine, the possibility that retrieval at altitude will correlate with poor outcomes remains unresolved.

The interval between injury and recompression and the altitude at which any retrieval takes place are usually accepted as important factors of prognostic significance. This review examines the relationship between time to recompression, mode of transport and outcome for 107 consecutive cases of DCI seen at this unit.

Overall, 27% of cases failed to recover fully on final assessment. These figures are broadly consistent with those previously quoted in Australasia.

There was no statistically significant evidence for improved outcome as a function of shortened interval from symptom onset to recompression. Similarly, there is no evidence for the efficacy of one transport mode over another. No attempt was made to relate severity of injury to outcome for non-CAGE cases, although there is often assumed to be a correlation.

All but one of the cases labelled “Acute Neurological DCI of the CAGE Type” were transported by helicopter. That these cases recovered fully to a similar extent as those of less dramatic presentations may indicate that both early presentation and low level helicopter retrieval will prove positive factors for full recovery in the more exhaustive prospective study underway at this unit.

Introduction

Recreational diving is an activity practised widely along the coast of NSW. The only medical recompression facilities available in the State in case of injury are located in Sydney at The Prince Henry Hospital and the Naval facility at HMAS PENGUIN. Consequently, many patients suffering from decompression illness (DCI) must travel long distances to reach definitive treatment.

A sophisticated network of retrieval services has developed in NSW using road, fixed wing and helicopter transport and these facilities are commonly used for the medical retrieval of diving injuries. The choice of the most appropriate transport can prove difficult. This is particularly true with respect to DCI where minimisation of both the time to recompression and the altitude stress experienced are generally accepted as of great prognostic significance. In addition, it has been suggested in the past that helicopter transport itself may be detrimental due to the effect of vibration on bubble formation and migration. This latter concern has received less attention since the advent of twin engine machines as a requirement for retrieval aircraft in this state.[1]

The primary purpose of this review is to examine the relationships between the interval from symptom onset to recompression, the mode of retrieval and outcome for a group of 107 consecutive DCI patients treated with recompression in our facility at Prince Henry Hospital. A recent review by Gorman and Harden[2] examined the reported Australasian experience with DCI in respect to outcome. Their report highlighted the apparent failure to follow-up patients adequately after treatment for DCI and the perhaps surprisingly high incidence of incomplete resolution of symptoms and signs following standard treatment algorithms. They also commented on the inability of the data to support the perceived wisdom regarding the efficacy of early versus late treatment.

The NSW retrieval system

Over the last fifteen years a sophisticated system of retrieval facilities has developed within NSW for the transport of critically ill and injured patients. Disparate services that developed independently and for distinct but overlapping purposes have been gradually brought under a common retrieval umbrella in an attempt to rationalise usage and improve efficiency. The result today is a network of services, overseen by the NSW Ambulance Service, through the Air Ambulance base at Mascot airport, capable of responding to a broad range of medical situations through activation of road, fixed wing and helicopter transport. As well as the familiar ground ambulance fleet, the system has at its disposal four Beechcraft King Air fixed wing aircraft and five rotary wing aircraft. The result is a flexible system capable of a rapid and graded response to medical emergencies throughout the State.

The choice of transport and level of medical care required for any particular patient can be a difficult one to reach. These decisions are usually made through discussion between the dispatching authority, the retrieval medical officer and the air ambulance co-ordination centre. They bring to this discussion clinical evaluation, retrieval experience and vehicle availability respectively and a retrieval strategy is usually quickly evident. This process is schematically shown in Fig 1.

The system can be accessed by medical personnel and the general public at several locations. Local medical services may contact the Hyperbaric Unit directly or arrange transfer through the NSW Air Ambulance Co-ordination Centre. The patient or other non-medical attendant usually contacts the Divers Emergency Service

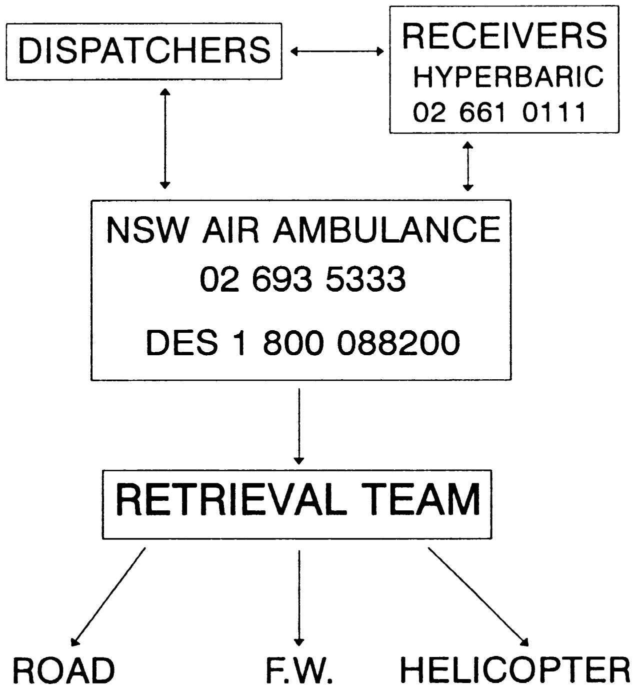

Figure 1. Schematic view of the NSW retrieval system and access numbers into the communication loop.

(DES), seeks advice from the Hyperbaric Unit directly or simply attends local medical facilities and indicates specialised assessment and treatment may be required. The system is designed to be flexible and cater to a wide variety of situations. The medical specialist on call for the Hyperbaric Unit is the final arbiter of matters concerning diving injury management while the retrieval medical officer manages the mechanics of transport.

In addition to those patients arriving through the retrieval system, many others present themselves to the unit having made their own transport arrangements. This group is included in our analysis and identified separately where relevant.

DCI has always been accepted as a time critical condition and the diver brought to the hyperbaric facility by the most rapid available means. In practice this has usually meant a road retrieval from Sydney and its immediate environs, low level (100 m) helicopter retrieval from scene responses in Sydney and sites up to 300 or 400 km away and sea level fixed wing transfer from further afield. These arrangements may be varied at night or in bad weather, when low level helicopter flights are hazardous, or when some transport modes are unavailable.

The original point of dispatch is shown in Table 1. This table is arranged so the geographical spread from north to south is reflected in the progression from top to bottom of the table.

TABLE 1

PLACES WHERE 51 RETRIEVALS STARTED

Tweed Heads
Byron Bay
Coffs Harbour
Port Macquarie
Taree
Newcastle
Gosford
Sydney Metro area
Wollongong
Shellharbour
Kiama
Shoalhaven
Huskisson
Ulladulla
Canberra
Pambula

The choice of transport seems, for the most part, to have been chosen with consistent logic. The use of the helicopter to retrieve four divers from the Sydney metropolitan region is explained through difficult patient access, while the road transfer of seven patients from Newcastle and the near South Coast may be of some concern. Possible altitude stress of relatively short ground journeys must be understood and an appreciation of road elevations on inward legs to the recompression facility is essential for rational planning of these retrievals. With road retrieval from the south, for example, the unavoidable rise up the escarpment north of Wollongong involves a maximum elevation of about 500 m. The practical result of these considerations is the arrival at our facility of patients by a variety of methods and time delays between symptom onset and recompression. It is the aim of this retrospective review to examine the impact of these variations on recovery.

Method

The records of patients admitted to the Hyperbaric Medicine Unit at The Prince Henry Hospital for the treatment of DCI from January 1991 to January 1993 were reviewed. Only those in which the diagnosis was in no serious doubt were included in the analysis.

A total of 131 records were examined in detail, of which 16 were rejected from analysis due to insufficient data being recorded or a failure to follow up identified.

Each case was classified according to retrieval method, time between symptom onset and first recompression and the presence or absence of continuing symptoms or signs related to DCI at six week follow up. A distinction was also made between disease of the cerebral arterial gas embolus (CAGE) type and all other forms of presentation.

Outcome at six weeks was analysed with the aid of a scoring system designed for this study. The aim was to score the patients into broad categories to obtain a gross estimate of the degree of functional impairment at last review. All scoring was done by the author after examination of the notes. Each patient was graded according to symptoms and signs at the six weeks follow up into one of five broad categories.

1 Well, no residual symptoms or signs
2 Minor symptoms of signs of little functional significance
3 Residual symptoms or signs leading to moderate impairment
4 Major incapacity
5 Dead

During the study period it was our practice to recompress using the United States Navy (USN) table 6 (Royal Navy (RN) 62) initially with extensions as appropriate, although occasional use was made of USN table 5 (RN 61). Follow up treatments were either USN Table 5 or 2.4 atmospheres absolute (ATA) for 90 minutes (14.90.10), according to clinical preference. The general treatment approach was to continue daily recompression until resolution of symptoms plus one further treatment or until no further amelioration in symptoms or signs was evident.

All patients were reviewed six weeks after discharge from the unit, either in the outpatients department or by telephone. Selected patients were also reviewed by the neurologist involved in their care at various intervals. Any changes in the patient’s condition after review at six weeks were not recorded for this study.

Results

The records of 107 patients were reviewed in detail. They were overwhelmingly male (78%) and relatively young (average age 29 yrs). From information volunteered and analysis of dive profiles, we estimated that 66% of patients had not seriously violated their dive tables. If no tables (or computers) were employed, the dive profile was compared with DCIEM Tables to determine violation or otherwise.

Fifty six patients arrived at the unit self referred. Of the 51 patients arriving via the retrieval system, the three available platforms were employed almost equally, as shown in Fig. 2.

For the purposes of analysis, the patients were

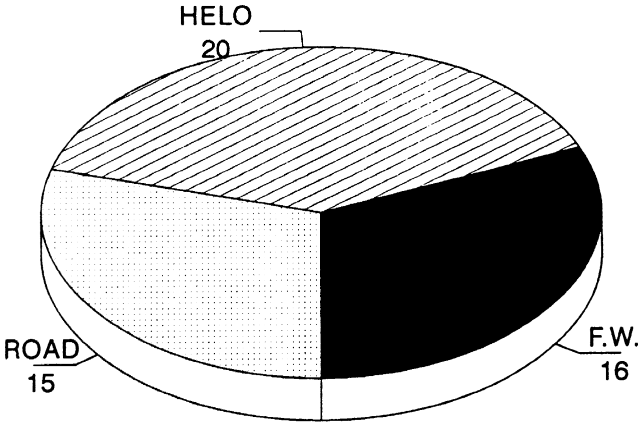

Figure 2. Mode of retrieval.

TABLE 2

OUTCOME AND MODE OF TRANSFER

Diagnosis	Mode	Discharge status 1	2	3	4	5
DCI	Helicopter	6	2			
	Fixed wing	13	3			
	Road	10	3			
	Self	40	13	2		
CAGE	Helicopter	9	1			2
	Fixed wing					
	Road		2			
	Self		2			
Total		78	25	2	0	2

Discharge status classification

1 Well, no residual symptoms or signs
2 Minor symsptoms of signs of little functional significance
3 Residual symptoms or signs leading to moderate impairment
4 Major incapacity
5 Dead

divided into two diagnostic criteria. This allowed those that presented with a CAGE type illness to be analysed separately, on the basis that such acute, central neurological disease of early onset may be prognostically if not pathologically distinct from other presentations of DCI. On assessment at arrival, there were 94 patients classified as DCI and 15 as CAGE.

Of the 107 patients assessed, 29 had an outcome score of more than 1. That is, over the two years under review the rate of complete resolution was 73%. Outcome category according to disease type and transport mode is shown in Table 2 as is the result of combining all transport modes. The small numbers in this review preclude any meaningful statistical analysis at this level.

Two patients died of dysbaric injuries (after transfer to hospital) during the study period. Both were in the CAGE group and arrived via helicopter. Two further patients were moderately impaired, both exhibited signs and symptoms of spinal DCI and presented for recompression more than 36 hours after first symptoms. Twenty five patients continued to exhibit minor symptoms and signs despite repeated recompression therapy. These varied from small persistent patches of dysaesthesia or anaesthesia to mild recurrent joint pains. Several complained of continuing general malaise and fatigue, not having fully recovered to pre-morbid levels of activity. The retrospective nature of this study invalidated any attempt to quantify different symptom patterns further.

In order to address the effect or otherwise of the time interval between symptom onset and recompression, this interval was related to the outcome at review and the results are graphically displayed in Figure 3. Similarly, the outcome classification is related to the transport platform in Fig. 4.

Discussion

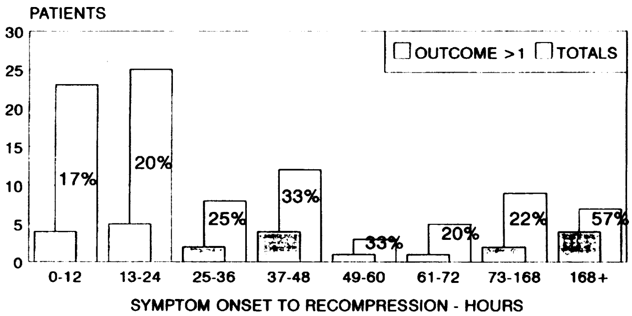

Figure 3. Outcome and treatment delay in 107 patients. Percentages show the proportion of each group with an outcome score of > 1.

The current review is necessarily hampered by the small numbers available for detailed analysis.

However, several interesting possibilities suggest fruitful areas for further examination.

The demographics indicate the group under review to be typical of the recreational diving community. Most significantly, they are young and male. That diving is an activity widespread through the state is supported by the

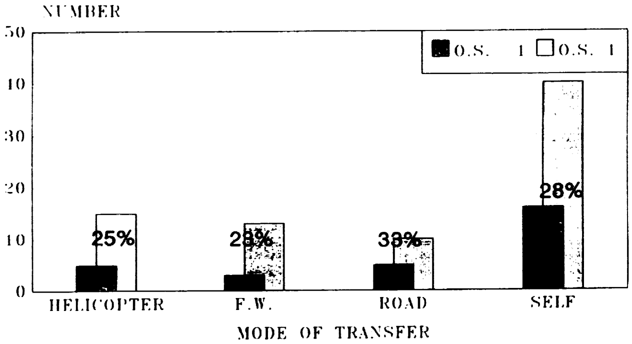

Figure 4. Outcome and transport mode in 107 patients. Percentages show the proportion of each group with an outcome score of > 1.

geographical distribution shown in Table 1.

The choice of transport method seems on this evidence to be reasonably rational. Those arriving from the far reaches of the state are doing so in fixed wing aircraft where their advantages of speed through the air and sea level flight capability are maximised. Helicopter retrievals are undertaken in an intermediate range where flexibility and a rapid response can minimise the time interval between injury and recompression (Table 2). The helicopter retrievals from within the immediate Sydney area represent both emergency rescue of those injured at inaccessible sites and those severely affected with central nervous system disease.

Road retrievals for the most part are short journeys with a less severely affected patient. A small number were transferred from the Wollongong and Newcastle areas. This is potentially unwise as both these journeys would require ascent to over 400 m at some time. This study has not attempted to specifically examine the outcome of these patients and so no comment can be made at this review as to the wisdom or otherwise of these transfers.

Table 3 compares the interval from onset of symptoms to recompression for each mode of transport. The striking feature is the difference between the average interval when the helicopter is employed and any of the alternatives. Clearly, this difference cannot be explained by vehicle capability alone and must be due at least partly to other factors not identified in this study. A number of possibilities suggest themselves including the deliberate delay by the patient before presentation, late recognition of the possibility of DCI and/or non-urgent transfer arrangements. Any of these factors may operate for those with a milder presentation where the need for early treatment may not be apparent either to the patient or his medical attendants. That transport problems due to physical distance alone are unlikely to be the major influence on long intervals from injury to recompression is illustrated by considering the self referred group. This group has clearly the longest interval to treatment but, in general, come from the Sydney region where distance is not a deterrent to presentation.

TABLE 3

ONSET OF SYMPTOMS TO RECOMPRESSION

Method of transport	**Time in hours**
Helicopter	4.9
Road	22.6
Fixed wing	29.7
Self-referral	(54.87)

The self-referral figure is brackets as it includes two extreme times, both more than 500 hours.

The implication is that many of the more dramatic cases of DCI and CAGE present to our unit via helicopter. Indeed, for CAGE patients in this study, all but one presented in this way. That there is little in our results to suggest that the helicopter group have a significantly worse prognosis than other groups implies either that severity of illness does not suggest poor outcome per se or that the increased risk is disguised by the much more rapid initiation of appropriate treatment in this group.

Examination of Fig 3 also poses some interesting questions. There is no suggestion on this small sample that early presentation is associated with a better chance of complete resolution, except perhaps for those presenting more than a week after symptom onset. To this extent, this data is in agreement with Gorman and Harden's review of the Australasian reported experience.

One logical result of this study is the heresy that perhaps DCI does not warrant emergency recompression at all and that such definitive treatment could be arranged at leisure! Clearly, such a conclusion is not justified on such meagre evidence. Indeed, an alternative view would be that the prognosis of the more severely affected individuals is improved by early transfer (by whatever means will expedite early recompression), and recovery is achieved to the same degree as when mild forms of DCI are treated after longer intervals. The strong suggestion in these data, that the early treatment group consists mainly of more dramatic presentations brought to the unit via helicopter, would support this hypothesis. These issues clearly require more investigation using statistically appropriate numbers before conclusions can be made with any degree of certainty. A combined prospective study is underway at this unit and at HMAS PENGUIN to this end.

Conclusion

A retrospective review of two years practice in diving injury retrievals has been undertaken as a pilot review before a more exhaustive prospective examination.

Few firm conclusions can be reached. The figures suggest there may be some reason to question the widely held beliefs that increasing delays from injury to treatment are associated with poor outcomes and that altitude stress during transfer will have a similar association with poor outcome.

A larger, prospective study concerning these and other related issues is currently underway and will be reported in due course.

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ARTICLES OF INTEREST REPRINTED FROM OTHER JOURNALS

WHY AMERICAN DIVERS DIED IN 1992
THE DANGER OF AIR EMBOLISM

Each year, the Divers Alert Network compiles a report analysing scuba diving fatalities among US citizens. For 15 years, Undercurrent has reported on those fatalities to help you improve your diving safety by understanding the causes of diver accidents. This year, in addition to reporting on the accidents themselves, we will conclude the series with an analysis of trends, including a look at whether the sport is getting safer. But first, a report on diver deaths due to air embolism in 1992.

More decompression illness but fewer AGEs

1992 was not a good year for scuba diving safety. There was a total of 876 cases of decompression illness, 6.5% more than 1991, and 96 fatalities, the highest since 1989. If there is a bright spot, it is in the incidence of arterial gas embolism (AGE), which has declined steadily in recent years, from 15.5% of total injury cases in 1990, to 9.2% in 1992.

That decrease is attributed to better education about the need for slow ascents as well as increasing computer use. It is much harder to streak for the surface when your computer is blinking and/or buzzing frantically for you to slow down. Only 6.3% of the decompression accident victims who were computer users developed AGE, as opposed to 12% of the table users.

Diver error is at the root of most AGE incidents. The typical AGE incident occurred during a shallow, no-stop dive within table limits, often on the first dive of the day. The predominant cause of embolism is too rapid ascent; time and depth exposures are not major contributing factors.

The thirteen people who died from embolism in 1992 fall into three broad categories: divers, usually inexperienced, who panic or allow themselves to run out of air; experienced divers making inherently risky dives; and those with medical problems predisposing them to embolism incidents.

A 42 year old man was diving with his l3 year old daughter in a mountain lake when the daughter encountered difficulty and became unconscious at 9 m (30 ft). The father brought her to the surface, where he went into cardiac arrest from an air embolism brought on by ascending too rapidly. The daughter died a few hours later at a hospital from brain damage caused by drowning.

In a case that demonstrates the failure of the buddy system, a 28 year old woman wearing a 60 cuft, 3,000 psi cylinder was paired with a male buddy with a 90 cuft, 3,300 psi cylinder on her second dive of the day from a coastal charter boat. They agreed she would return alone to the boat when her air became low. When the male buddy returned to the boat, she was not there. Her body was found the next day at 16.5 m (55 ft). Death was the result of a cerebral air embolism caused by a too rapid ascent due to insufficient air.

A 49 year old woman was diving with her husband in a quarry. Both had limited experience (18 dives). They had exceeded their planned depth when the husband signalled to ascend. He assumed that his wife was with him, but when he discovered she was not, he returned to her. Again he ascended, thinking she was with him. At the surface he could not find her. Her body was found two days later in 38 m (127 ft) of water. She had drowned after developing an air embolism due to rapid ascent.

A 41 year old man, diving in 6-7.5 m (20-25 ft) of water with two friends, indicated he was having problems. They all surfaced. He told his friends he would snorkel back to shore alone. When they surfaced again two minutes later, they found him about 15 m (50 ft) from shore, face up and unresponsive. His cylinder was empty. Death was due to air embolism; he had run out of air and may have held his breath while ascending.

On his third dive of the day, a 43 year old man developed problems while surfacing from 19.5 m (65 ft) and sank to the bottom, where he was found by other divers who were surfacing. Resuscitation was not possible. Death was caused by drowning due to air embolism. In one of two AGE fatalities during training, a 26 year old man was making his second certification dive when he encountered difficulty with his air supply. He was assisted by his instructor, but would not buddy breathe; instead, he began to ascend rapidly. He became unconscious at about 3 m (10 ft). He was rescued promptly, but there was great difficulty getting him into the boat. He died of a cerebral embolism caused by rapid ascent. There was 900 psi in his cylinder and his regulator was functioning normally.

Risky dives and AGE

A 36 year old man doing an advanced open water training dive to 27 m (90 ft) in a mountain lake ran out of air during ascent. He attempted buddy breathing on an octopus but made a rapid ascent. By the time he reached shore, he was in cardiopulmonary arrest. An autopsy revealed air in cerebral vessels over wide areas, with massive effect.

A 37 year old man was diving with a companion to 70 m (232 ft). During ascent, at 64.5 m (215 ft), he became unconscious and lost his regulator. The buddy brought him to the surface, where an ambulance was called. Nine minutes had elapsed since the start of the dive. Although resuscitation was attempted, he was essentially dead at the surface. The instantaneous death and the air in his epicardial veins suggest that death was due to coronary, rather than cerebral, air embolism, caused by rapid ascent.

Several other deaths from AGE also belong in the category of risky dives. In one case (one of 21 deaths during technical diving), a 34 year old man was diving on a 40.5 m (135 ft) deep wreck on a 38% oxygen-nitrogen mixture. He was found unconscious on the bottom. The cause of unconsciousness may have been an oxygen seizure, considering the depth and mix.

In another deep wreck dive, a 43 year old male was diving a wreck at 51 m (171 ft), using two cylinders with independent regulators. As he was ascending with his buddy, he indicated a problem, then became unresponsive and finally unconscious. His buddy dropped his weight belt for him, which allowed him to rise. He floated face down at the surface while his buddy completed his obligatory decompression stop. Examination revealed that one cylinder had only 150 psi, the other 2,700 psi. During his free ascent to the surface, the victim suffered an air embolism. It is likely that nitrogen narcosis or hypercapnia (CO_2 retention) was the reason he did not successfully transfer breathing systems.

In one of six cave-diving deaths in 1992, a 41 year old man was exiting a cave when his buddy noticed he was no longer following. The buddy found the diver unresponsive, with his regulator out of his mouth. He was not able to rescue him. The buddy made his ascent without decompression stops, resulting in decompression sickness. The deceased was found 82.5 m (275 ft) into the cave system, up against a ceiling at a depth of 30 m (100 ft). Death was caused by air embolism.

Two fatalities from AGE were related to previous health problems. A 40 year old woman who had undergone heart surgery but was subsequently cleared to dive was making her first dive since surgery with a group of divers unknown to her. Her buddy noticed she was having difficulty during descent. He began to ascend back toward her when she sank past him headfirst with her regulator out of her mouth. Although she was rescued and CPR was attempted on the boat, she succumbed to air embolism.

A 42 year old man with a history of pulmonary problems was diving with his girlfriend in 18 feet of water when he began acting in a confused manner, removing his regulator from his mouth, before lapsing into unconsciousness. Drowning was due to cerebral air embolism. Although there were only these 13 deaths from air embolism in 1992, there were 76 total AGE cases, giving an AGE survival rate of 83%.

Heart attack

Reporting on scuba diving fatalities is a long Undercurrent tradition. Last month, we looked at deaths due to air embolism, which have declined in incidence over the years as training has improved and computer use has increased. This month, we take a look at cardiovascular disease as a factor in scuba fatalities. Thanks to Divers Alert Network for compiling the data. Any errors in reporting are ours alone.

In 1992, five divers died from heart attacks while diving; in four other cases, cardiovascular disease (often previously unrecognised) was a contributing cause of a drowning death. All of the divers whose immediate cause of death was heart attack were past 40, indicating caution for divers in this age range. DAN recommends a comprehensive examination to detect the presence of coronary artery disease. All divers, particularly those over 40, should have a routine of aerobic exercise, four to five times a week if possible. In people who don't exercise regularly, physical exertion can precipitate a heart attack but regular exercise can help prevent it. Many divers think recreational diving requires only limited exertion; but the heart responds to excitement, stress, and other emotional and physical conditions that we are hardly aware of. As the following case histories demonstrate, the idea that exertion must be strenuous to cause a heart attack is a fallacy.

A 41 year old man preparing to dive with friends in a freshwater lake made a short swim and then switched from his snorkel to his regulator. He took a few breaths, then rolled over on his back without descending. He was immediately rescued by his companions, who found him in cardiac arrest. He was dead on arrival at a local hospital; an autopsy disclosed the presence of coronary artery disease.

In a similar case, a 45 year old man diving alone off a beach was discovered unresponsive. He was dead on arrival at the hospital. The autopsy showed the cause of death to be coronary atherosclerosis (hardening and degeneration of artery walls).

A 41 year old man making an ocean dive was found with his regulator out of his mouth. He did not respond when his companions offered him an alternative air source; when they brought him to the surface, he was in cardiac arrest. The autopsy disclosed a previously unknown narrowing of the aorta caused by rheumatic fever many years before.

A 53 year old man who had undergone a triple coronary artery bypass was cleaning the bottom of his boat using rented scuba gear. After he failed to surface, searchers found him on the bottom with the regulator out of his mouth. An autopsy ruled that the cause of death was an acute myocardial infarction (heart attack).

While hunting abalone, a 71 year old man reported to be in excellent physical condition failed to surface. His younger companion found his body. The medical examiner stated, "The cause of death is...atherosclerotic heart disease....The decedent developed severe myocardial ischaemia (blood flow blockage) due to marked narrowing of all major coronary arteries. As a consequence, he probably lost consciousness and ... aspirated sea water".

In one of four deaths where the immediate cause was drowning with cardiovascular disease a significant contributor, a 57 year old executive who had accompanied his fiancee and instructor disappeared on an open water training dive in water with 1.5 m (5 ft) visibility. His body was not recovered for over 24 hours. Autopsy disclosed severe coronary artery disease.

A 50 year old man was at 15 m (50 ft) with his son during a certification check-out dive when the son noticed that his father's regulator was out of his mouth and he was unresponsive. He could not be resuscitated at the surface. His drowning was a result of either syncope (interruption of heart action), cardiac arrest at depth, or possibly a seizure brought on by his failure to take prescription medication for past brain tumour surgery. Autopsy disclosed coronary atherosclerosis.

A male born in 1944 drowned while diving, due to insufficient air. He had a medical history of hypertension and an enlarged heart, and two days before diving had experienced an episode of chest pain severe enough to make him stop his car while driving.

A 32 year old became separated from his two companions during an ocean dive. When his body was found, his tank still contained air and his regulator was in his mouth. Autopsy disclosed heart disease that may have caused irregular heart rhythms, leading to loss of consciousness and drowning. Marijuana use was listed as a contributing factor.

The conclusion this time is easy: get more exercise. Next month the lessons are more varied, as we review diver deaths due to drowning.

Drowning

In the last of our series on why divers die, we review deaths due to drowning, which is by far the most commonly described cause of death among scuba divers. Analysing these cases can help us avoid making the same mistakes. Thanks to DAN for compiling the data. All errors and interpretations are our responsibility.

There is a significant likelihood that many "drowning" cases are not categorised correctly. The term "drowning" is a catch-all, often applied indiscriminately to almost any in-water death. The NOAA *Diving Manual* does not even reference the term! The second edition of *Diving and Subaquatic Medicine* (Edmonds, Lowry, and Pennefather) defines drowning as "the death of an air-breathing animal due to aspiration of fluid", in other words, inhaling water, which can cause some or all of the following symptoms: laryngeal spasm, vomiting, hypoxia, loss of consciousness, flooding of the lungs, and eventual circulatory arrest.

The diagnosis of drowning thus should probably be applied only to those cases in which diver death results from asphyxia. However, when a diver dies in the water, unless an autopsy is performed by a physician or coroner who is knowledgeable about hyperbaric medicine, the autopsy may not correctly identify the actual cause of death. To someone who has perhaps never heard of air embolism, the fact that a diver was under water and came out dead makes it easy to suppose that he drowned.

Even within this framework, the following accidents should provide some clues as to how to avoid getting into similar situations. Twenty-seven divers were reported to have drowned in 1992 after having run out of air. Most (or all) of these deaths appear to have been entirely avoidable, through either proper training or better use of diving techniques and equipment.

A significant number occurred due to lack of planning, "going for it." What else can you say about not carrying line-cutting devices, cave or wreck diving reels, or other safety gear? Twelve divers died after becoming trapped in caves, wrecks, or fishing line. The dangers of cave and wreck diving are taught in every beginning scuba class, along with the necessity of carrying at least one line-cutting tool such as paramedic's shears or a knife. It is worth remembering.

Another 11 divers died after losing mental control because of alcohol, drugs, panic, or getting narked. At least a third of these drownings occurred at or near the surface. Apparently Bob Halstead, captain of the Telita, is right: the surface is about the most dangerous thing a diver has to face.

An overweight 53 year old male surfaced with his female companion about 300 m (yards) down current from their small boat. He swam off in the wrong direction and she was unable to correct his course. She found him floating face down on the surface; he drowned after having run out of air.

In another unsuccessful surface swim, a 40 year old man became separated from his buddy after surfacing a good distance from their charter boat. When the crew recovered his body, his tank was empty. He was unable to maintain positive buoyancy and had drowned after running out of air. There is no mention of what happened to his weight belt. Shouldn't a diver who empties his tank on the surface know where the rest of the atmosphere is, and how to access it by flipping over on his back or using his snorkel? Panic is suspect here. If you are in trouble on the surface, only panic could make you forget to inflate your BC, drop your weight belt, turn over on your back, or use your snorkel.

Several other cases can be attributed to bad judgment, diver error, and drugs. A 32 year old man diving in a current-swept, 3.6 m (l2 ft) deep river became separated from his companions. Rescue divers located his body. He was wearing a drysuit with 17.3 kg (38 lb) of weight: in addition, he had collected 2.3 kg (5 lb) of fishing lures. He evidently ran out of air and was unable to surface because of the excess weight.

A 30 year old man who had never been certified (one of eight uncertified deaths) was diving using borrowed gear, including a regulator with deteriorated diaphragms. He inhaled sea water through the regulator at the surface, panicked, and fought with a companion who tried to help him. Autopsy disclosed the presence of marijuana in his system.

Another uncertified individual, a legally intoxicated 27 year old using barely functional borrowed equipment and wearing ear plugs, persuaded friends to drop him in the centre of a flood-stage river with zero visibility. A fisherman found his body lodged in a tree a few days later. The alligator bites were post mortem.

There were some equipment-related deaths, and it is likely that other deaths attributed to drowning were also caused by equipment problems that got out of hand. For instance, the most recent issue of the *South Pacific Underwater Medicine Society Journal* reviews 553 reports of diving incidents and accidents from 1989 through 1992, including fatalities, in the Australia-New Zealand region. There were 175 equipment-related problems, including 69 malfunctions. Of these, 18 incidents involved inaccurate or "sticking" tank contents gauges (SPGs). Also, 30 regulator incidents were reported, including free-flow, ruptured hoses, and two problems with mouthpieces. In half of the incidents, the regulator had been recently serviced. Inaccurate SPGs and mouthpiece problems are particularly relevant to several cases described below.

A 32 year old man developed problems with his regulator at the beginning of the dive. The boat captain told him to switch to his octopus, but that did not relieve the trouble. The boat captain entered the water and recovered the unconscious diver. The mouthpiece was in his mouth, but detached from the regulator. The other regulator also was lacking a mouthpiece, which suggests that the retaining ties binding the mouthpieces to the regulators had failed. This death was described as due to defective equipment, but a more rigorous analysis would lay the blame on poorly serviced equipment and, more important, inadequate pre-dive gear checking by the diver himself.

Technical divers, or those divers who equated the term "technical" with "deep", were not exempt from drowning as a cause of death. Most of them seemed to die on the bottom with their booties on and their tanks dry. There were 21 deaths among those doing technical-level diving in 1992: 11 were trained technical divers, and 10 were recreational divers attempting technical-level dives without the proper training or equipment. A trained technical diver using mixed gas (allegedly l7% oxygen, 50% helium and 33% nitrogen) had penetrated a deep wreck and become separated from his companions. He was found on the bottom with his tanks empty. He was using his breathing mixture to inflate his dry suit, a practice which may have resulted in hypothermia.

In an example of untrained divers attempting technical-level dives, two divers going for their "personal best" depth records planned a dive past 60 m (200 ft). Neither returned.

In one of six cave-diving deaths (three among trained cave divers, three without cave training), a 23 year old certified cave diver lost contact with the guideline in zero visibility during a very difficult penetration. His body was recovered several days later. Death was due to drowning after running out of air.

Two divers planning to spearfish entered a frozen quarry without lines, safety divers, or any kind of topside support. They became lost, ran out of air, and drowned.

A freshwater wreck diver failed to return after a dive to a 27 m (90 ft) deep shipwreck. His body was found sitting in the engine room with his gear off but his regulator still in his mouth. Apparently he had removed his gear in an attempt to enter a confined space, but lost visibility and simply remained where he was until his air ran out.

What can we learn from these tragedies? Mostly things that we should already know but may not be practising. Drugs and diving are not a good combination. Don't run out of air underwater. If you run out on the surface, don't panic: get buoyant as soon as you can, stay buoyant unless you intend to descend, flip onto your back or use your snorkel, drop your weight belt if necessary and if you inhale any water, cough it out or swallow it. In virtually all the surface incidents, and most of the underwater incidents except those in which both buddies got lost in an overhead environment, having an attentive buddy on hand probably would have made the difference between life and death.

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SUB OCEAN SAFETY

A newly organised, non-profit group responds to the emergency medical needs of Miskito Indian divers

There is a land where nitrogen eats the spines of hunter/divers and everything you have been taught about safe diving is rejected as a cowardly waste of time and money. To dive here, a man must face nameless sea demons who randomly strike the life from young divers. Ignorance and greed have built this system; it will be righted with education and a helping hand; but first it must be revealed to you.

Concealed on the remote Miskito Coast of Honduras, hidden from time, lies the jungle village of Kalquira. Its people survive in cruel paradox, with one foot in Eden and the other in hell. Here, where tropical fruit drips from trees, lives the largest contingent of commercial scuba divers the world has ever known, 95% of whom have been totally untrained in diving physics.

Kalquira is an average coastal village in the Gracias a Dios province, where 45,000 Miskito Indians live and 5,000 young men dive for the lobster industry. The lobster and conch diving industry has employed 90% of the workers here for the last 20 years and totally dominates the economy. Modern technologies have displaced the old ways of hunting on the sea and now a grim price is being paid. 125 lobster divers live in Kalquira, 45 of whom are suffering from paralysis induced by decompression disease, an illness caused by breathing compressed air under water for too long at too great a depth. Their symptoms include loss of sphincter and bladder control, impotence and rotting skin ulcers; their life expectancy runs from two to three years, or less.

Almost all these men have families. Many victims are only in their late teens, most are in their twenties and early thirties. Of the "healthy" men who still dive, 100% exhibit classic symptoms of decompression disease, from joint deterioration through loss of equilibrium. They are all teetering on the brink of paralysis whenever they work. This nightmare has infected every community on this ancient coast, where once productive fathers rot away and desperate wives turn to prostitution to feed their children. Thousands have been injured; everyone is affected. Here is a primitive land, where sea devils possess the souls of crippled divers and witches burn men's spines to exorcise them. There is a better way.

This malignant pandemic of decompression disease has roots too complex to fall into any traditional relief categories and has grown unchecked. In answer to this challenge, ***Sub Ocean Safety***, a non-profit organisation, has risen.

Forged from the impossible dreams of hyperbaric medical director Dr Thomas Millington and diver/publisher Robert Izdepski, SOS has become a driving force in diving safety and environmental action, tested under fire in one of the most remote and dangerous regions of this planet.

In 1991, Dr Millington, himself, delivered a Vickers mono-place single lock recompression chamber to the Moravian Mission Clinic in Ahuas, Honduras, and began publicising the decompression crisis there, ultimately capturing Izdepski's attention in 1993.

Izdepski, with his son, Jesse, immediately went to Mosquitia to investigate, and since the revelations of that first shocking investigation, his *Universal Diver Magazine* (then THE WORKING DIVER) has diligently funnelled equipment and expertise into SOS, working extensively at the magazine's own expense. "This was more than a magazine story to me," says Bob, "It was the ultimate diving horror from the dark ages. I staked everything on this issue and publicly vowed to change the lobster industry for the better. That's what we're doing."

In March of this year, with financial assistance from the Association of Diving Contractors, Hyperbaric Oxygen Therapy Systems Inc., and TACA Airlines, Dr Millington, expedition videographer Jorge Torres, Robert Izdepski and another of his sons, Caleb Windship, successfully transported a 4,000 lb., 48" double-lock recompression chamber (donated by CAL DIVE, INTERNATIONAL) from Guanaha Island to the Moravian Mission Clinic at Kalquira, retracing the route sailed by Columbus in 1502.

The chamber was loaded aboard a Guanaha lobster boat, through arrangements with "Coping", a lobster boat owners' association. Bob and Caleb went to sea with it, heading east toward Cape Gracias A Dios.

Near the Honduran/Nicaraguan border, the ship was prohibited entry into Kalquira by a shallow bar at the mouth of a lagoon. Stranded offshore in building seas, resourceful actions saved the day; the chamber was pressurised with scuba tanks, manually cast overboard and floated through the surf into a crocodile infested lagoon, where it was dragged 12 miles to the shores of Kalquira. Then, using Egyptian technologies and Louisiana riggin', Bob, Caleb and 50 Miskito Indians slaved for two more days, inching the chamber 100 yards from the water into the clinic.

Meanwhile, back in Guanaha, Millington and Torres shot several videos of lobster divers in action, above and below the water, made an "on board" instructional video of a decompression incident of paralytic bends and its subsequent resolution using in-water oxygen therapy, interviewed the Coping association leaders and filmed the inner workings of a lobster processing plant. Torres (winner of the World Press International award for photographic arts) then joined the Izdepski team in Mosquitia to video some epic diver interviews.

This most recent SOS expedition was successful in many more ways than one. After convincing Coping that the *SOS safety and environmental solutions* were not only feasible, but made economic fishing sense, Coping provided practical and financial assistance to the expedition. "We realise that the boat owners did not plan out this evil, they simply did not have the knowledge or incentives to resolve it. We provided both by working with them, rather than just pointing fingers, and together we were able to find mutually beneficial solutions. The complexities of these problems break down when reasonable people communicate. I respect the boat owners for their many accomplishments, and I am glad that we could show them how they could increase profits, in both the short and long terms, by increasing safety aboard their vessels and working toward a sustainable fishery. It was most satisfying." says Izdepski.

Word of this amazing expedition is just getting around now and it has already attracted internationally recognised authorities to the SOS Board of Directors. We now seat Dr David Youngblood (specialist and clinical director of hyperbaric medicine), Jolie Bookspan, PhD. (research physiologist studying the effects of heat, cold, altitude and immersion on decompression), Professor Bernard Nietschmann of UC Berkeley (leading authority on coastal indigenous peoples and marine habitats), David Cressy (former New Orleans City Attorney), as well as Dr Millington (Director of Hyperbaric Medicine, Pleasant Valley Hospital), publisher/saturation diver, Robert Izdepski and his wife Susan. who runs a private school.

This unique blend of expertise has produced a specific prescription for this third world crisis; a crisis that reaches far beyond the shores of Mosquitia.

Reports of expanding epidemics of killer decompression disease have reached SOS from around the world, from Colombia and Brazil to Borneo and Viet Nam; wherever advancing scuba technologies have impacted third world fisheries without provisions for diver education, families are destroyed by the spectre of paralysis and death. The social and economic costs of this world-wide pandemic are astronomical already, and growing exponentially. The solutions lie with emergency hyperbaric medical treatment, diving education, sustainable fishery planning and enforceable regulations. Enter, SOS.

SOS is responsible for two recompression chambers in Mosquitia, diving and medical training (there are now four dive schools in Mosquitia thanks to the Moravian Church, instructor Bob Armington, and SOS), instructional videos, the recent implementation of lobster fishing seasons and proposals in front of Honduran government regulators now, including: requirements for the certification of divers and boat captains to standards, air compressor regulations, required on-board oxygen and medical supplies, diving depth limitations, diver physicals, mandated diver use of standard safety equipment, depth and pressure gauges, watches, etc., lobster size limitations, and a ban on harvesting egg bearing females.

On March 28th of 1995, raw footage from the SOS expedition video was shown by Izdepski to a gathering at the Undersea and Hyperbaric Medical Society's Gulf Coast Chapter meeting, astounding that "case hardened" audience with revelations of atrocities unknown and scenes of decisive action. Bob was subsequently honoured by an invitation to speak at the banquet, unexpectedly given donations to SOS by UHMS and the American College of Hyperbaric Medicine, and was further honoured with an additional invitation to speak and show the expedition video at the International UHMS meeting in Palm Beach, in June 1995.

SOS now controls four recompression chambers that can be used to reverse diver paralysis. Only one is operational. The chamber in Kalquira still lacks an air compressor, radios, air and oxygen hoses, 0_2 regulators and miscellaneous equipment. The other two chambers await funding for repairs and transportation. Organisational funding is desperately needed to improve communications.

Only now do we take time from our efforts to ask for help. This monster is just too big and dangerous for us to continue our struggles alone; in fact, our silence is in danger of becoming counterproductive to our causes. Though adverse to asking for funding, our recent successes make it more honourable: I hope you will understand, there is simply no other way.

We have done all we can in getting this far. If you wish to assist us in any way, please contact us, we need your help now.

Strengthened by its recent victories and bolstered by its growing support, SOS is in a position to use its Mosquitia experiences to continue its work around the world; wherever greed and ignorance propel the horrible exploitation of divers and their environment. We invite you to put flesh and bone into our strategies, enlist in our bold expeditions, inform us of regions where unbridled exploitation rules the sea. We have only won some battles, to win the war we need you to send us where we cannot go and put your strength in our hands.

For information contact:
Sub Ocean Safety
PO Box 834 Lacombe, LA, USA, 70445
USA free call 1-800-867-3807, Phone 504-882-7875
Fax 504-882-6416

This announcement follows on from the article, *Paralysis, starvation or famine: the Miskito dichotomy continues* by Bob Izdepski published in the SPUMS Journal in March (1995; 25 (1): 45-51).

SAFE LIMITS: AN INTERNATIONAL DIVE SYMPOSIUM

AN OCCUPATIONAL MEDICINE POINT OF VIEW

David Smith

In this paper, I intend to put an occupational medicine view on some aspects of health and safety in the diving industry.

Accidents are a bit like theatre. The scene is set, the players are all waiting in the wings and the props are in place, just waiting for the curtain to rise. There is a point at which the accident becomes inevitable. If only we were gifted with foresight, we could rewrite the script so that the accident could not happen.

But health and safety is about having foresight and processes have been developed to identify high risk situations which lead to the inevitable accident. Risk management is the process.

No one would dispute that diving is a high risk industry, but I am far from convinced that all employers (operators) in the diving industry apply the principles of risk management that are expected in other workplaces such as those in the metal and construction industries. I suspect this is because this industry grew out of a sport and is still perceived as one by most people. Nevertheless, formal risk management strategies are essential in any high risk operation.

This is a four step process:

1 Hazard identification,
2 Risk assessment,
3 Application of control measures and
4 Re-evaluation of controls.

Hazards are the things that have the potential to cause an injury or illness. For any particular type of diving they are usually well known. Risk is the likelihood of an adverse outcome eventuating from hazards present. Risk is dependent on many factors involving the workplace, the process, the equipment or the people, and can be increased or reduced by modifying any of the factors.

By applying a risk assessment process, high risk activities will be revealed, enabling appropriate modifications to be made. Thus, an unguarded sheet metal guillotine, operated by a single foot pedal stands out as a high risk operation because of the forces exerted, the proximity of hands to the workpiece and the ease with which a foot control can be operated inadvertently. Yet, with appropriate guarding, two hand activation and operator training, the process can be rendered safe. Managing risks is what makes any industry safe and of course not managing them can have tragic consequences.

Occasionally this process turns up an activity which appears to carry a high risk for which effective controls are not available. This then must be viewed with grave suspicion and should probably not be undertaken. Mixed gas diving is one such activity which appears to have little benefit for the cost of a substantial level of risk. I do not believe the risks involved here can be properly controlled outside of the armed services. This of course is a sensitive issue which puts any advocate of prohibition at some risk themselves.

Of more concern, because of the greater number of participants, are those parts of the industry where the general public becomes involved. The diving workplace is unique in that the public, which is always an unknown equation, wanders through using the equipment. The risks in diving are high enough for the experienced but rise exponentially when the inexperienced become involved.

Here the risk is high partly because the people side of the equation is so variable. Take just one aspect, health and fitness as an example. Asthma, epilepsy and diabetes are not uncommon maladies and neither is the overuse of alcohol and other drugs. Selection procedures which include properly conducted medical examinations by qualified practitioners, should afford a high degree of control for the risks posed by these chronic diseases. Where there is reliance on tick box health questionnaires, sometimes applied after the person has paid and is enroute to a dive site, the degree of control can be far from adequate.

For some snorkelling ventures, not even this is undertaken. Thus, the health of the participants is completely unknown.

I suspect that the lack of appropriate selection procedures is part of the reason for the high number of fatalities in snorkelling which should be the lowest risk end of the industry. Three deaths in recent months suggests a major problem. Proper selection procedures alone will not be enough. There must also be adequate supervision. One person in a boat "looking after" twenty or more snorkellers (some in dark wetsuits) must be inadequate. So inadequate, that in one case, the operator was not even sure that the person was missing. Surely such a situation cries out for improved safety performance.

Once an accident or incident has occurred, the best way to prevent a recurrence, is to initiate a thorough investigation to determine not just what went wrong but why. This should be an essential part of the control strategies for every industry. This process should occur at various levels appropriate to the incident, but a formal process within the workplace must always be put in train. Other investigations required by law will come in as the grade of severity increases. Unfortunately, nothing goes cold faster than the trial of a diving accident. This workplace is fluid in more than one sense. People disperse, equipment is not always kept and the workplace is constantly changing. So speed in initiating an investigation is essential.

For the Division of Workplace Health and Safety, getting appropriate information seems to be a major issue. Where decompression sickness is concerned the time interval between dive and onset can sometimes make it difficult for the employer (dive operator), whose duty it is to notify the authorities, to know in every case that the incident has occurred. Hence, notification in such cases breaks down.

The second problem is getting information that a person has been admitted to a treatment facility (hospital). Ethical considerations prevent notification by hospital authorities where there is no statutory obligation to do so. A dive related illness is not a notifiable disease under the Health Act and since the hospital is not the employer, there is no obligation on the treating doctor under health and safety legislation either. Again, the notification procedure breaks down.

A formal requirement on all parties to notify these incidents would greatly assist in getting an investigation underway quickly. This obligation already exists for the employer. It may be necessary to make it a statutory obligation for treatment facilities too, in order to absolve them of their ethical dilemmas.

The third problem occurs when there has been a fatality. The fact that there is an established diving post mortem procedure set out by the College of Pathologists seems to be unknown by many practitioners undertaking coronial autopsies. Hence, there is a risk of missing vital evidence as to the actual cause of death. How would a cerebral arterial gas embolus be identified for example? I am hopeful that the Division of Workplace Health and Safety can be a catalyst for improving the standard of autopsy carried out in diving deaths in future.

Finally, I have been concerned for some time about the risk for those Japanese tourists who fly home (or somewhere else) soon after a dive experience. How many cases of decompression illness occur in this group? I doubt that we know. There could be many which are unrecognised by local Japanese practitioners, particularly if the patient fails to make the association that the symptoms may be dive related and does not mention the fact that diving had been undertaken. Surely as an industry a standard and immutable period of 24 hours before flying could be built into diving packages to minimise the risk.

I have tried to outline some concerns from an occupational physician's perspective. There is obviously room for improvement in the health and safety practices of the dive industry generally and in some aspects in particular. Also current procedures for investigation of an incident still have problems which call for resolution. I hope that by raising these concerns in this forum, some practical strategies can be discussed which lead to ***prevention*** . That is what health and safety is all about.

Dr David Smith is Principal Medical Officer, Division of Workplace Health and Safety, Queensland. He has been working in the occupational health and safety field with the Queensland Government for 14 years.

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DIVING INCIDENTS: ERRORS DIVERS MAKE

Christopher Acott

Introduction

Safety in any activity is dependent upon an adequate knowledge of the risks associated with participation in that activity. Diving is an equipment orientated sport in a diverse and dynamic environment. Knowledge of the problems associated with the use of this equipment and of the common errors made while in the marine environment are important aspects of diving safety. Accident researchers in anaesthesia, aviation and the nuclear power industry have shown that 80-90% of accidents in systems involving human interaction with equipment were due to human error.

An error is a "flawed" action or intention and occurs when a planned sequence of actions or intentions fail to result in an intended outcome. Errors are a normal part of everyday cognitive function. Most errors are trivial, occur repeatedly, are recognised and corrected before they cause harm. Accidents are unpredictable and often products of errors and unlikely coincidences interacting at an inopportune time when there is "no system flexibility".

Because of the unpredictablity of accidents, prevention of future accidents from retrospective analysis is imprecise and difficult. It is easier to predict and prevent errors, rather than accidents, because errors are methodical, take on predictable forms and can be classified. Elimination of all errors is impossible but minimisation of their effects is possible. Therefore, if the common errors in diving can be identified measures can be designed to minimise or eliminate these errors and so improve safety.

Psychologists have classified errors into active and latent. Latent errors may occur before the time of the accident and are the "scene setters", while active errors are usually immediate precursors to the accident. Active errors can be further subdivided into either contextual, modal or psychological error.

CONTEXTUAL ERRORS

In this classification the error and events are described. This type of approach is useful for gathering data on particular tasks, however, it can not predict the occurrence of any particular type of error.

MODAL ERRORS

In this classification errors are classified as either those of omission, repetition, substitution or insertion. This classification can be used for the calculation of error probabilities but will not predict how the error will manifest itself.

PSYCHOLOGICAL ERRORS

In this classification errors are related to cognitive function and are predictive of outcome. These are either knowledge based, rule based, skill based or technical based errors. Knowledge based errors are due to the lack of or inadequate knowledge on how to perform a particular task. They can, therefore, be minimised or eliminated by using continuing education and quality assurance programs. Rule-based errors are due to the application of an inappropriate rule to solve a particular problem or the poor application of a rule that has been designed to minimise the effects of a particular occurrence. These can be eliminated by using a written structured check list prior to diving (cf. the pilot's cockpit drill). Skill based errors are due to inattention and not responding to events while on "auto pilot". These errors are commonly called lapses or slips. These type of errors can be minimised by the over learning of a particular skill. While technical errors are due to faulty technique in the execution of a task and could easily be described as either rule or knowledge based errors.

Incident reporting

Incident reporting is the reporting and learning from your mistakes and the mistakes of others. Incident reporting is not interested in culpability or criticism but in the process of error. It is a method of identification, classification and analysis of human error in the context of its contributing and associated factors and does not try to measure the absolute occurrence of a particular error or match one error to a particular outcome, however, it can identify "clusters" of errors. It is a method of risk assessment. Error identification is risk identification.

It is not a new concept. An Englishman first thought of the idea in the late 19th Century. However, it was first used in aviation in 1940 by the US Army Airforce to improve safety and now is an established part of the aviation industry. Data gathered from aviation incidents are used to reconstruct flight accidents and so are a major tool in flight accident investigation. Incident data also have been responsible for pre-flight check protocols and cockpit design. Incident reporting is also an established part of medicine (particularly anaesthesia) and the nuclear power industry.

In recreational scuba diving a diving incident is defined as any error or unplanned event that could, or indeed did, reduce the safety margin for the diver on a particular dive. The error may have been made by anybody associated with the dive and can occur at any stage during the dive. The incident may also include equipment failure.

Why incident reporting and not accident reporting?

Firstly, counting the dead or maimed are poor measures of how well "things are going".

Secondly, when a Coroner or other "official" body is involved, the reports of the event tend to show what should have happened rather than what did happen. Unfortunately, the "blame model" still operates in recreational diving.

Thirdly, most accidents have multiple components and it is difficult to identify and apportion responsibility to these various components.

Fourthly, there are not enough accidents and deaths to make "statistical sense" of the data. For each accident there is many more incidents, hence the power of incident reporting.

And finally, the development of strategies to prevent future accidents from retrospective analysis of past accidents is imprecise and difficult. It is easier to predict and prevent errors rather than accidents because errors are methodical and take on predictive forms.

Is incident reporting data accurate?

The data are anonymous and so there are no methods by which it may be checked. However, because it is anonymous the reporter is not restrained in any way (i.e. by feeling foolish or by legal retribution) when describing the details of what happened and so will report the situation as accurately as they can. It is highly unlikely that the reporter would lie, there is nothing to be gained by doing so. Some incidents may be reported by 1 or 2 divers, but as incidents are analysed and classified the same incidents will be identified by the details and the dates they are received.

Because of the unconstrained nature of incident reporting its application to diving will provide a comprehensive picture of current diving practice and demography. The safety implications of such a technique are obvious, identification of the most common recurring errors in recreational diving will help in their prevention and elimination. A medical analogy would be a randomised biopsy to each of the body's organs to see how things are going, but incident reporting is much less painful!

Incident report form

A Diving Incident Monitoring Study (DIMS) was commenced in 1988. Continued analysis of the reports received has led to the incident report form being modified. These incident report forms have been distributed throughout the Australian and New Zealand diving community. The latest version is reproduced on pages 158 and 159, modified from the Safe Limits Proceedings. Divers are encouraged to fill out one of these forms as soon as they have witnessed or have been involved in an incident; it only takes about 2 or 3 minutes.

Knowledge based errors (Type 1) are represented in the DIMS form in the "factors contributing" by: inexperience in diving, not familiar with the diving conditions, judgement error, failure to understand equipment and dive table.

Rule based errors (Type 2) are represented by: failure to check equipment, poor dive planning, poor communication and lack of a buddy check.

Skill-based errors (Type 3) are represented by: haste and inattention.

Technical errors (Type 4) are represented by poor dive planning and insufficient training.

The latent factors/errors (Type 5) in diving are represented by: anxiety, weather conditions, poor physical fitness, poor maintenance and servicing of equipment, inadequate supervision, drug or alcohol intake and a lack of medical clearance to dive.

Discussion

The factors contributing to the first 1,000 incidents reported to the DIMS are ranked in Table 1, according to frequency with which they were ticked on the report forms.

Knowledge or rule based errors predominated in the first 10 listed contributing factors. This has important implications for training: using this incident report data, areas that need emphasis can be identified and concentrated on in training. The incident report technique was used to examine the common errors that occur in the out of air situation in recreational diving.

Out of air

859 reports were analysed. 168 (19.5%) involved an out of air problem. Fifty seven (35%) of these incidents involved "diver harm", this constitutes 13.2% of all incidents associated with morbidity. These data correlate with fatality data in that 17% of diving fatalities were associated with an out of air situation.

Out of air problems are not confined to the inexperienced diver. Over 75% of the divers had greater than a basic qualification. Inexperienced divers do, however, have a greater chance of injury. Of concern is that 11 diving students had problems with their air supply and that four of these involved morbidity (Table 2).

Table 3 lists the morbidity or "diver harm" associated with the out of air situation. Table 4 lists the contributing factors and type of error involved.

Thirty two percent of these out of air problems were due to active rule-based errors while 11% were active knowledge-based errors.

Failure to check the contents gauge featured in 33% of the out of air incidents. This type of error could be classified as either rule or knowledge-based. However, either failure to check or an inaccurate contents gauge was responsible for 48% of all the out of air incidents. It is essential then that corrective strategies be introduced. Measures to minimise these incidents include audible alarms (set at 50 bar) in both the tank pillar valve and the diver's contents gauge, a thorough pre-dive contents gauge check and a requirement for the recalibration of contents gauges with an annual regulator service (contents gauges are not required to be recalibrated after purchase). Training programs should be modified to stress the importance of monitoring the contents gauge throughout the dive. Other suggestions have included the carrying of a small spare (pony) cylinder, but similar problems would be associated with it as with the main air supply. Failure to check that the air supply was turned on, failure to check the cylinder's contents and the regulator's air hoses, mouth piece and second stage featured in 32% of incidents and would be just as applicable to the pony cylinder. If a diver failed to check his or her main air supply before a dive will he or she check the spare supply? I think not! A fully maintained and checked pony bottle would be of use in the sudden loss of a diver's air supply but this constituted only 5% of the out of air incidents.

Six percent of incidents were due to equipment failure (first stage regulator problems and kinked hookah

TABLE 1

CONTRIBUTING FACTORS IN THE FIRST 1000 INCIDENTS REPORTED TO DIMS.

Contributing error	Number	Type of error
Error in judgement	249	1
Inexperience	224	1
Inattention	212	3
Poor dive planning	196	4
Failure to check	176	2
Haste	143	3
Insufficient training	129	4
Anxiety	124	5
Failure to understand equipment	109	1
Not familiar with diving conditions	109	1
Poor communication	96	2
Poor physical fitness	83	5
Weather conditions	78	5
Lack of a buddy check	64	2
Poor maintenance of equipment	51	5
Failure to understand the dive table	42	1
Inadequate supervision	40	5
Sea sickness	37	3
Lack of medical clearance to dive	34	5
Poor servicing of equipment	34	5
Drug or alcohol intake	25	5

Responses are ranked according to the frequency they were ticked on the report form. They are also categorised into the type of error. Type 1 = Knowledge-based. Type 2 = Rule-based. Type 3 = Skill-based. Type 4 = Technical. Type 5 = Latent.

DIVING INCIDENT REPORT

Diver Emergency Service

Deaths in diving are preventable. Reporting of events leading to "near–misses" can give insight into the causes of accidents and deaths. Incident reporting is part of this process. It is being used with great success in aviation and medicine. We believe that study and analysis of diving incidents will lead to improvement in equipment, training and safety.

Filling out this questionnaire may at times prove tiresome, but we urge you to do it as soon as practicable following the dive. Don't waste your valuable experiences – share it for the benefit of us all.

Definition of a Diving Incident

A Diving Incident is any error or unplanned event that could, or indeed did, reduce the safety margin for a diver on a particular dive. The error may have been made by a diver, either yourself, your buddy or someone else. It may also be due to equipment failure. Most incidents don't cause any harm, but reporting such incidents will give valuable information when considered with other such incidents.

This form will be distributed worldwide, so a broad range of incidents will be analysed. Diving organisations will receive regular feedback on incidents collected.

Please DO NOT identify any person involved.

Please DO NOT report heresay incidents.

Dr Chris Acott, MB, BS, FFARACS, DipDHM, from the Diving and Hyperbaric Medicine Unit at the Royal Adelaide Hospital, Adelaide, South Australia will be coordinating these reports.

Please return the completed form to:

Diving Incident Monitoring Study
GPO Box 400
ADELAIDE SA 5001
AUSTRALIA
61 08 224.5544/5116

THE INCIDENT ITSELF

All the following relate to the dive involved in the incident, however they don't have to be filled out by that diver involved, but by the person noticing the incident.

1. Whose incident was it?

yours ☐ your buddy ☐ someone else's ☐

2. When was it detected?

preparation ☐ during dive ☐ exit ☐
entry ☐ ascent ☐ following exit ☐
descent ☐

3. Did any harm result to anyone?
Yes ☐ No ☐

4. Do you think any of the following factors contributed to the incident (you may need to tick more than 1):

anxiety about the dive ☐	error in judgement/incorrect decision ☐
inexperience in diving ☐	poor communication ☐
weather conditions ☐	failure to understand equipment ☐
poor physical fitness/fatigue ☐	failure to understand dive table ☐
failure to check equipment ☐	poor maintenance of equipment ☐
haste ☐	malfunction or failure of equipment ☐
inattention ☐	drug or alcohol intake ☐
poor dive planning ☐	lack of medical clearance to dive ☐
poor servicing of equipment ☐	inadequate supervision ☐
sea sickness/nausea/vomiting ☐	lack of a buddy check ☐
insufficient training ☐	poor visibility ☐
not familiar with diving conditions ☐	strong current ☐
nil ☐	

5. Did the incident occur whilst under training?
Yes ☐ No ☐

6. What influence did the incident have on the dive plan?

none ☐	delayed the dive ☐
aborted the dive ☐	changed the plan ☐

7. Did the incident involve (you may need to tick more than one):

out of air situation ☐	equalization problem on ascent ☐
rapid ascent ☐	equalization problem on descent ☐
omission of decompression stops ☐	giddiness/vertigo ☐
*flying altitude after diving ☐	multiple ascents/descents/bounce diving ☐
problem at safety stop ☐	loss of buddy contact ☐
buoyancy problem at Deco. stop ☐	marine animal ☐
anchor retrieval ☐	panic ☐
misreading of decompression tables/computer ☐	

*** Flying or going to altitude > 300 m within 24 hours of last dive.**

8. Was the diver involved:
a diving student ..... ☐ untrained .... ☐ certified diver .... ☐

9. Diver certification level:
basic .... ☐ open water .... ☐ advanced .... ☐
divemaster .... ☐ instructors .... ☐ commercial .... ☐
not known .... ☐

10. Sex:
Male .... ☐ Female .... ☐
Diver's Age .... yrs Not known .... ☐

11. Which country did the diver train in?
Australia .... ☐ New Zealand .... ☐ USA .... ☐
UK .... ☐ Japan .... ☐ Not Known .... ☐
Other ....

AIR SUPPLY

1. Air Consumption:
ran low .... ☐ out of air .... ☐ not a problem .... ☐
Octopus used .... ☐ not known .... ☐ buddy breathing .... ☐
low contents (<100 bar)/empty tank at start of dive ...... ☐

2. If there had been an alternative air source (ie a Pony Bottle, "Spare Air") would it have helped in the situation?
Yes .... ☐ No .... ☐ Not known .... ☐

3. Regulator and air supply:
didn't check contents gauge regularly . ☐ 1st stage problem .... ☐
air supply not turned on .... ☐ 2nd stage problem .... ☐
hose rupture .... ☐ contents gauge inaccurate/failed .... ☐
unable to read contents gauge at depth ☐ mouth piece problem .... ☐
problems with octopus reg .... ☐
problem with regulator despite frequent servicing .... ☐

4. Air consumption this dive greater than previous dives:
Yes .... ☐ No .... ☐

BUOYANCY

1. Buoyancy problem:
Yes .... ☐ No .... ☐
overweighted .... ☐ underweighted .... ☐
problem due to B.C.D .... ☐ weight belt problem .... ☐
air used frequently to maintain buoyancy .... ☐

2. Buoyancy Jacket:
not worn .... ☐ inflation device failed .... ☐
inflation device not connected correctly ☐ unfamiliar with its use/operation .... ☐
unable to vent vest to slow down .... ☐ confusion: inflate/deflate .... ☐
vest leaked .... ☐ name of vest ....
vest provided inadequate buoyancy .... ☐ Buddy couldn't inflate/deflate diver's jacket ☐
vest spontaneously inflated/inflator jammed .... ☐

EQUIPMENT INVOLVED IN INCIDENT (you may tick more than one)

borrowed .... ☐ tank .... ☐ hired .... ☐
bed .... ☐ new .... ☐ depth gauge .... ☐
mask .... ☐ fins .... ☐ other .... ☐
specify ....

DIVE TABLES/COMPUTER

1. Dive tables used:
None .... ☐ USN .... ☐ RN .... ☐
NAUI .... ☐ DCIEM .... ☐ BASSETT .... ☐
BSAC/RNPL .... ☐ PADI .... ☐ Unknown .... ☐
Other: specify .... ☐

2. Was a dive computer used?
Yes .... ☐ No .... ☐

If so:
stopped working .... ☐ unable to read/numbers confusing .... ☐
inaccurate .... ☐ forgot to activate it .... ☐
Make: .... Model: ....

Does the diver concerned take any medications?
Yes .... ☐ No .... ☐ Not known .... ☐
Specify: ....

Does the diver concerned have any health problems?
Yes .... ☐ No .... ☐ Not known .... ☐
Specify ....

Do you think this incident was preventable?
Yes .... ☐ No .... ☐ Undecided .... ☐

DESCRIPTION OF INCIDENT

Please describe the incident in your own words. Include in detail any factor which you believe may have contributed to, or minimized, the incident.

Suggest any measures which you feel might be employed in the future to prevent such an incident happening again.

If more than one incident occurred, please fill out a separate form for each incident.

The DIMS form allows space for the reporter to describe the incident in their own words.

Unfortunately the copy of the DIMS form supplied was not suitable for reprinting in the Journal. This reproduction has the questions arranged in the format that they appeared in the Safe Limits Proceedings, not in the layout used by divers.

TABLE 2

THE QUALIFICATIONS OF DIVERS INVOLVED IN OUT OF AIR SITUATIONS

Qualification	Numbers	Associated Morbidity
Diving Student	11	4
Basic	23	11
Open Water	65	27
Advanced	26	3
Dive Master	7	2
Dive Instructor	14	2
Untrained	11	4
Not stated	11	4

TABLE 3

MORBIDITY ASSOCIATED WITH OUT OF AIR SITUATIONS

Morbidity	Numbers
Decompression sickness	24
Cerebral gas embolism	10
Pulmonary barotrauma	6
Salt water aspiration	4
Near drowning	3
Hypoxia underwater *	2
Pulmonary barotrauma/Salt water aspiration?	1
Decompression sickness?	1
Not stated	6

* Rescue resulted in a cerebral gas embolism

hoses) in that they would not have been prevented by a pre-dive check or regular servicing. Another 14% could have been included in this category (inaccurate contents gauges, free flowing second stages and inability to read the contents gauge because of poor design) but all could be detected with a thorough pre-dive check and, therefore, are not “pure” equipment failures.

The frequent use of the power inflator to maintain buoyancy was only identified as a cause of a diver becoming out of air in 5 incidents; this is a fault of technique. The 3 incidents of divers being unable to read the contents gauge were due to limited visual acuity as well as poor equipment design.

There were twelve reports of vomiting underwater; 3 resulted in the loss of the diver’s air supply. Diving while nauseated (from whatever reason) is dangerous.

TABLE 4
CAUSES, CONTRIBUTING FACTORS AND TYPE OF ERROR INVOLVED IN THE OUT OF AIR SITUATION

Cause	Number of incidents	Type of error
Did not check contents gauge	55	KB/RB
Contents gauge inaccurate	25	RB
Empty/depleted tank before dive	18	RB
Air not turned on	12	RB
2nd stage problem	12	RB/EF
1st stage failure	8	EF
Inattention and or increase in air consumption	6	KB
Air hose rupture	5	RB
Air frequently used to maintain buoyancy	5	KB/TF
Change tank size	5	KB
Mouth piece problem underwater	4	RB
Vomiting obstructing mouth piece	3	* B/LE/Chance/ RB/KB
Unable to read contents gauge	3	EF/LE
Air consumption/poor dive plan	3	KB
Hookah air hose kinked	2	EF
Scooter/inattention	1	LE/Chance
Tank contaminated with silica	1	RB

Types of error

KB: Active knowledge based errors. These errors are due to inadequate knowledge or experience.
RB: Active rule-based errors. These errors are due to the failure to apply a rule designed to avoid error or minimise adverse outcome.
EF: A problem occurred as a result of equipment failure. The equipment had been appropriately maintained and checked prior to use.
TF: Technical fault. An error due to a faulty technique.
LE: Latent error.
Chance: An incident occurred due to a chance event.

Table 5 lists the type of ascent and associated morbidity that occurred following the out of air problem.

From these data a rapid buddy breathing ascent and a rapid non-breathing (i.e. exhalation only) ascent are associated with the same degree of morbidity. Even when the ascent rate is controlled, buddy breathing ascents had a 30% associated risk of morbidity. Controlled octopus breathing or exhaling non-breathing ascents have less morbidity than buddy breathing ascents. These data show that buddy breathing ascents are unsafe.

If possible, a controlled octopus breathing ascent is the safest option in an out of air situation. However, this

TABLE 5

TYPE OF ASCENT AND ASSOCIATED MORBIDITY

Type of ascent	Numbers	Morbidity
Out of air	168	57
Out of air/rapid ascent	89	52
Out of air/non-rapid ascent	79	5
Out of air/octopus/rapid ascent	21	9
Out of air/buddy/rapid ascent	14	7
Other rapid ascents	54	36
Out of air/octopus/non-rapid ascent	39	1
Out of air/buddy/non-rapid ascent	10	3
Non-rapid ascents	30	1

TABLE 6

THE FAULTS

Air supply and regulator problems
Empty tank
Air supply not switched on
Tape on pillar valve
Regulator mouth piece was torn

Buoyancy Jacket
Power inflator not connected
Inflator hose mouth piece toward base
Emergency dump valve jammed t
Tank was loose in the BCD harness

Depth Gauge
Maximum depth indicator was not zeroed

depends on the diver's buddy being both close and aware of the diver's predicament.

Analysis of the first 1000 incidents reported to DIMS have shown that failure to check is a common error made by divers. Also, the out of air data show that a failure to check either the air supply during or at the commencement of the dive featured predominantly. Equipment problems are implicated in diving accidents and a pre-dive equipment check is an essential part of diver preparation. However, failure to check the equipment is hardly mentioned in accident data. It was, therefore, decided to do a study of the thoroughness of the pre-dive check.

At random, divers at an annual dive exhibition were asked to perform their normal pre-dive check on some diving equipment (buoyancy compensating device (BCD), tank, regulator with octopus, contents gauge and depth gauge with maximum depth indicator) which had been doctored to represent common equipment faults noted in the DIMS data. No information was given on how many faults there were and there was no time limit, however, the time taken was noted by an observer (the author). The diver's qualifications were not asked for.

There were nine (9) engineered faults and these were divided into 3 sections, those dealing with the air supply and regulator, those with the buoyancy jacket and those with the depth gauge, see Table 6.

Fifty five divers participated. Two divers identified all the faults, 4 divers detected 8 of the 9 faults while 4 divers failed to detect any fault. An empty tank, no air or a faulty BCD dump valve can have potential fatal consequences. Only 3 divers noted all these faults.

Twenty three divers noted all the air supply faults but only 4 of these the additional torn regulator mouth piece.

Only 8 divers identified all the buoyancy jacket's faults.

The time taken to complete the check varied between 2 and 10 minutes with the average being 5 minutes. Anecdotal data suggest that the time taken to do the pre-dive check in this study was considerably longer than the time taken to do an on site pre-dive check.

A similar study was performed on the same equipment but with only 4 engineered faults (maximum depth indicator was not zeroed, the power inflator was not connected to the BCD, the tank was turned off and the air supply was only 50 bar). The divers were asked to provide their qualifications, but not which agency trained them. Fifty four percent of the divers tested detected all 4 faults (just over 50% of the dive masters and dive instructors tested identified all 4 faults). This study again showed the lack of ability of divers to perform an adequate pre dive check.

These studies showed that the divers tested did not perform a thorough pre-dive check on the equipment supplied. With the prevalence of a failure to check in diving incidents an easy to remember simple guide or a written pre-dive check list is needed. Once devised then its thoroughness will need to be tested.

Conclusion

The data presented shows that a failure to check equipment is an important contributing factor in diving incidents. This type of error can be classified as either a rule-based (failure to follow the rule of performing an adequate pre-dive check or to monitor the air supply during the dive) or a knowledge-based error (divers not being adequately taught a pre-dive check protocol or that the air supply should be monitored continuously throughout the dive).

Failure to check is a common error made by divers in recreational scuba diving.

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DIVERS ALERT NETWORK (DAN) ACCIDENT DATA

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(Presented by Chris Wacholz)

Abstract

The Divers Alert Network (DAN) was started in the USA in 1981. In February 1991, International DAN (I-DAN) was established to organise existing dive medical emergency and other membership services internationally in order to give worldwide access to information about the availability of recompression and other facilities for diving accidents. DAN USA is a non-profit, recreational diving safety organization, based at Duke University Medical Center in Durham, North Carolina, and is also the current headquarters for International DAN. DAN's primary mission is for the benefit of the diving public through information and emergency telephone hot-lines; research and education; and to act as an advocate for diving safety. The DAN USA diving emergency referral network has over 130 hyperbaric chambers and 520 referral physicians linking injured divers with qualified physicians and suitable hyperbaric facilities.

In 1992, 1,776 emergency calls were received by DAN USA and 11,511 calls were taken on the medical advice phone number line resulting in over 18,000 dive related medical questions. A detailed report on 465 diving accident cases representing 53% of the total 1992 cases (876) was published in January 1994. The 876 total included 225 decompression sickness (DCS) Type I, 577 Type II and 76 arterial gas embolism (AGE) diving accidents. DAN has answered over 60,000 medical or safety information calls and over 12,000 emergency calls in the last decade. Since 1989, DAN also has collected and studied diving fatalities. DAN produces from its accident database an annual Report of Diving Accidents and Diving Fatalities. In 1992, a total of 96 recreational scuba fatalities were reported. Forty seven of these fatalities were certified basic or open water, 11 were advanced, 8 were dive masters, 2 were instructors, and 6 were divers who were uncertified to dive. The total number of US scuba diving deaths increased by 29 from the 1991 total. At least 90 scuba related deaths have been reported for 1993.

Only 50% of DCI affected divers called for assistance within 12 hours, due primarily to the failure to recognise symptoms or denial. While 35% of all injured divers received oxygen, only 15% received both oxygen and fluids, the two most widely recommended first aid measures. It is hoped that DAN's oxygen training program, introduced in 1991, will help improve oxygen use in the future. To date, October 1994, over 1,600 scuba instructors have been trained to teach oxygen first aid and over 25,000 lay scuba divers have been trained to provide oxygen to injured divers.

Introduction

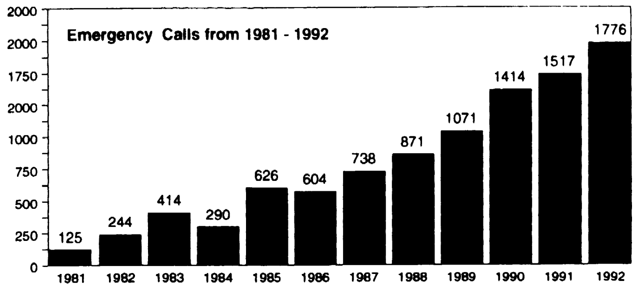
Divers Alert Network (DAN) began operations in 1981; originally as a public medical telephone advisory service for scuba (self-contained underwater breathing apparatus) divers and as a clearinghouse for information on dive accidents. Since that time DAN has grown to include dive safety and medical education, research, insurance and the promotion of products and services that enhance diving safety for the general public.

DAN provides a significant public service that has increased in scope each year. Emergency and non-emergency medical question calls have increased from 757 calls in the first year to over 15,000 calls today. DAN's 24 hour emergency and daytime medical advisory services are the single most important public safety net for an estimated 3 million recreational divers in the United States. DAN's dive medicine and first-aid education programs have trained over 1,700 physicians, health care workers and lay persons to effectively recognise and care for injured divers. This education effort, along with DAN's organization of the majority of United States' diving medical facilities and physicians into an effective national dive medical response system, benefits the entire diving public. DAN's research efforts have produced the world's largest and most complete data base and analysis of dive accident information which is freely available to the public.

The DAN logo and phone number is widely reprinted without restriction throughout the world. The 919-684-8111 number is predominant in North America and the Caribbean while other regional International DAN numbers are promoted in Europe, Japan and Australia.

DAN insurance, which began in 1987, was created to solve the public health problem of providing for the very expensive emergency evacuation and medical treatment cost of treating injured scuba divers, which are often not covered by major medical insurance plans in the United States. Air evacuation companies generally will not fly without many thousands of dollars deposited up front. What follows is a description of DAN's programs and epidemiological data.

FIGURE 2

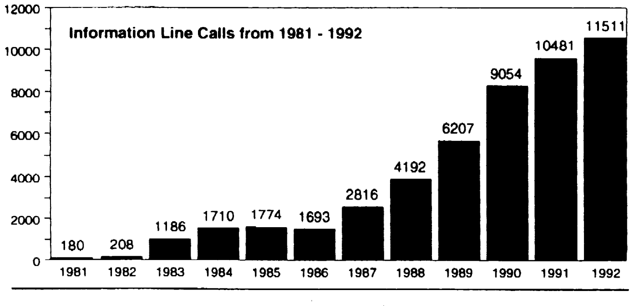


Medical telephone advisory services.

All DANs throughout the world operate or promote a 24 hour emergency telephone line which any diver or physician may call from anywhere in the world for free consultation and referral to appropriate medical facilities. DAN also operates a daytime, Monday to Friday, telephone service which divers and health care workers may call to ask non-emergency medical questions, e.g. how a particular health problem (such as asthma) might affect the individual's risk while scuba diving. Other topics include questions on general safety procedures and other concerns of the diving public. The medical question line is operated between 9 a.m. and 5 p.m. US Eastern Standard Time by trained diver emergency medical technicians (EMTs) and nurses, backed up by DAN's volunteer on-call physicians. Anyone may call DAN for assistance whether they are a member or not and there are no fees for the service.

Throughout the United States, Canada, and the Caribbean, DAN's North American emergency and non-emergency telephone referral service is organised into seven regional co-ordinating centres, 136 hyperbaric chamber facilities and 520 dive medicine referral physicians. All of these facilities and physicians hold dive medical credentials and accept patient referrals on a voluntary basis. While they may bill the patient for services rendered, these on-call physicians and facilities receive no compensation for their participation in DAN's network, and they agree to accept DAN's referrals without regard to the patients' ability to pay.

FIGURE 1



Calls to the DAN 24 hour emergency service are generally answered within five minutes through the use of a dedicated pager system. All callers receive some assistance within five minutes of making contact with the 24 hour emergency number. During the daytime when call volume is heaviest, DAN's diver EMT staff field all calls. This often involves consulting with a resident or, if need be, an attending on-call dive physician. After hours calls are fielded by the resident on-call physicians backed up by the attending on-call medical staff. This system also provides a public service by training physicians in diving medicine, both through DAN's orientation education as well as practical service as resident on-call DAN physicians.

Upon request, DAN also provides free training and dive medicine textbooks to any physician in the Caribbean or in developing nations frequented by recreational divers. DAN's emergency care posters and first-aid manuals are distributed free of charge to hospital emergency rooms throughout the US, Canada, and the Caribbean.

DAN has aided over 62,000 divers since the non-emergency medical and emergency telephone lines were initiated in 1981. In 1992 DAN serviced 1,776 emergency calls and 11,511 non-emergency medical question calls. DAN periodically surveys callers to determine what percentage are supporting members and what percentage is the general public. Periodic surveys indicate the use of DAN's advisory telephone services by non-members averages as much as 75 percent.

Decompression illness injuries

The Divers Alert Network has been publishing a yearly report on recreational scuba diving accidents since 1987. DAN collects its accident reports through the DAN network of hyperbaric treatment centres located throughout the United States, US Territories and popular dive sites frequented by American divers. DAN also utilises its emergency telephone service and information hot-line in acquiring reports of diving injuries and fatalities. DAN USA does not follow reports on non-US citizens. At present DAN only collects and follows recreational scuba injuries and recompression chamber treatment. There is no way to estimate the number of divers who do not choose to seek treatment for dive related symptoms. Other injuries such as marine life trauma, sinus, middle ear or pulmonary barotrauma are not counted nor reported on by DAN at this time.

TABLE 1

TOTAL REPORTED CASES

Year	Total
1986	562
1987	624
1988	565
1989	678
1990	738
1991	820
1992	876
1986-1992	**4863**

Since 1986 the number of decompression illness (DCI) cases has slowly increased. It is believed that this increase in reported accidents is in some part due to increased awareness of decompression illness and knowledge about the symptoms of decompression illness as well as use of the DAN service. Individuals who were unaware of symptoms may have never sought evaluation and treatment previously. This has been evidenced by the increasing number of calls on the DAN emergency and information telephone lines. The present collection system has been in place for almost six years and has continued to increase in efficiency and effectiveness resulting in a higher number of reported cases. The total population of scuba divers at risk for decompression illness is unknown so no accurate incidence rate can be determined.

Only 50 percent of DCI affected divers called for assistance within 12 hours, due primarily to the failure to recognise symptoms or denial. In 1992, 35 percent of all injured divers received oxygen first aid. Oxygen is an extremely effective first aid measure which can reduce the symptoms and severity of injuries when applied immediately after symptoms start. It is hoped that DAN's oxygen training program introduced in 1991 will help dramatically improve oxygen use in the future.

The more general term DCI is commonly being used to describe compressed gas injury related to scuba diving. This term is replacing more specific diagnostic terms such as arterial or cerebral arterial gas embolism, which is the result of air trapping or voluntary breath holding on the part of the diver while ascending through the water column. Symptoms of arterial gas embolism (AGE) are generally immediate in onset. The most common symptoms are seizure, unilateral or bilateral paralysis, change in the sensorium such as a semiconscious state or total loss of consciousness and other cerebral symptoms. Decompression sickness (DCS) is also a specific diagnostic term which covers an entire spectrum of symptoms but is not very descriptive. DCS generally refers to symptoms which come on sometime after making a dive to 9 m (30 ft) or greater with significant time exposures. Typical symptoms are pain, numbness and tingling, weakness, dizziness, headache and extreme fatigue.

Since the mechanism of bubble formation and injury is different in DCS and AGE, they are reported on separately rather than under the general term of DCI. The frequency of occurrence for each diagnosis is also different. There are many similar aspects in the dive profiles of divers who suffer AGE or DCS. DCS is further broken down into two "types" of symptoms. DCS I is referred to as pain only DCS occurring in the joints and tissue of the arms and legs. DCS II refers to symptoms which are more likely to be related to the central nervous system such as numbness, paraesthesias and pain of the trunk.

Injured divers represent a wide range of ages. This age distribution probably represents the population of active divers. Approximately 75% of all injuries occur between the ages of 25 and 44 years of age. For the first time, there were three reports on injured individuals who were 65 or older. There are fewer accidents reported below the age of 20 or at the age of 50 or above. There may not be as many certified divers in these other age groups, or they may dive in a different pattern than the majority of the injured divers. When these age groups were rated in terms of the severity of their decompression illness, injuries were also less severe below the age of 20 and at the age of 50 or above.

The percentage of active female divers is not known, but approximately 25 percent of all dive injuries have been to females since 1987. A 1989 random sample of insured DAN members had a response rate of 69.5% with 27% of all respondents being female. The percentage of female dive accidents could simply mirror the percentage of active, non-injured female divers, or they may under-represent female participation in diving if more than 25-

TABLE 2

DISEASE DIAGNOSIS

Final Diagnosis	1987%	1988%	1989%	1990%	1991%	1992%
DCS I	17.4	22.4	22.5	22.0	17.8	17.4
DCS II	63.3	60.4	64.5	62.5	69.8	73.3
Air Embolism	19.3	17.2	13.0	15.5	12.4	9.2
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.9**

TABLE 3

DISTRIBUTION OF DIVER AGE

Age	1987%	1988%	1989%	1990%	1991%	1992 %
10-14	0.7	0.7	0.3	0.2	1.4	0.2
15-19	4.1	1.5	2.8	3.3	2.8	2.8
20-24	10.4	10.1	10.1	8.2	7.8	10.1
25-29	19.3	23.1	24.0	22.9	16.1	16.1
30-34	23.3	23.9	22.0	22.5	23.7	22.8
35-39	22.2	14.6	14.6	20.5	22.3	20.9
40-44	11.9	13.1	12.3	11.8	12.6	14.0
45-49	4.1	7.1	7.4	5.0	7.8	7.5
50-54	1.1	4.1	4.3	3.1	3.0	2.6
55-59	1.1	0.7	2.8	1.1	1.4	0.9
60-64	1.9	1.1	1.3	0.7	1.1	1.5
>65	0.6	—	—	—	—	—
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.1**	**100.0**

TABLE 4

SEX OF INJURY CASES

Sex	1987 %	1988 %	1989 %	1990 %	1991 %	1992 %
Female	24.1	21.6	26.1	26.4	25.2	29.2
Male	75.9	78.4	73.9	73.6	74.8	70.8
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

27% of active divers are females.

Lack of diver experience does play a role in DCI as it does in other types of sports injury. There are differences between males and females as to when DCI occurs in their dive career. A higher percentage of female DCI injuries occurs in the first year or within the first 20 dives (31%). Only 27% of male DCI injuries occur in the first year, and 20% occur within the first 20 dives. Fifty-eight percent of the male DCI injuries and 75% of all female DCI injuries will have occurred in five years or less of starting to scuba dive. It is possible there are fewer females who have been diving as long as males, and the small percentage of injuries is an artifact of the smaller female population. It could also be that males and females have different styles of diving. At present, it is unclear why a higher percentage of DCI occurs in females earlier in their dive career. Lack of diving experience or infrequent diving does appear to contribute to diving injuries.

It has been suggested that an episode of DCI in an individual may predispose that person to a second injury.

Previous DCI and its relationship to a second illness is difficult to qualify. Certainly, any injury that has long-term residua or injuries that have affected the brain and spinal cord must be taken very seriously when individuals wish to return to diving. The percentage of individuals who have second or third DCI injuries is relatively constant in the injury population. The 1989 random survey of the DAN membership revealed that in a group of insured, safety conscious divers, the percentage of a decompression incident was very low such that only 2.6% had ever had DCI. There may also be some predisposition to DCI in certain individuals. It may also be that individuals refuse to change the type of behaviour that contributed to their first episode of DCI.

It is difficult to generalise the injury population data that DAN acquires each year to the healthy uninjured population. Trends in diving injuries do not reveal how much of a role individual events play in creating DCI. The relationship of most dive events remains statistical and not causal in nature. Single dive conditions or factors will rarely cause a dive injury. More commonly, several factors will generate the circumstances that produce DCI.

Each diver assumes some risk when they enter the underwater environment and perform physical tasks requiring mental and physical fitness. Avoiding hazardous situations and behaviours is important in injury prevention and health maintenance. The acquisition of diver experience and knowledge in terms of additional education and practical diving experience leads to more responsible and injury free divers. Although the total number of treated cases reported appears to increase each year, the increase is not significant when compared to the increase in the number of new divers entering the sport.

US diving fatalities

The Divers Alert Network began collecting scuba fatality information in 1989. In 1990 DAN joined with the University of Rhode Island (URI) to produce a yearly report that combined both injuries and scuba fatalities. The University of Rhode Island has been tracking scuba deaths since 1970. There have been 2,296 scuba deaths recorded since that time. There was an average of 130 deaths per year during the 1970s compared with an average of 90 deaths in the 1980s. It is believed that better training and a decrease in the number of uncertified individuals participating in scuba are factors responsible for reducing the number of scuba fatalities.

The distribution of age and gender of scuba fatalities is similar to that of the injuries but with some important differences. In 1992, 13.6% of the scuba fatalities were 50 years of age or older compared to 21% of the injury cases. The percentage of female scuba fatalities has increased over the last three years and is now nearly the same as that found in scuba injuries. It is known there is a higher incidence of certain diseases and other illnesses in the older population. Approximately 53% of all fatality cases held only basic or beginning level certification. This includes 6.8% that were still undergoing training.

The majority of deaths in scuba diving are attributed to drowning. The most frequent cause of drowning death is an insufficient air supply. This may be

FIGURE 3

YEARLY UNITED STATES RECREATIONAL DIVING FATALITIES 1970-1992

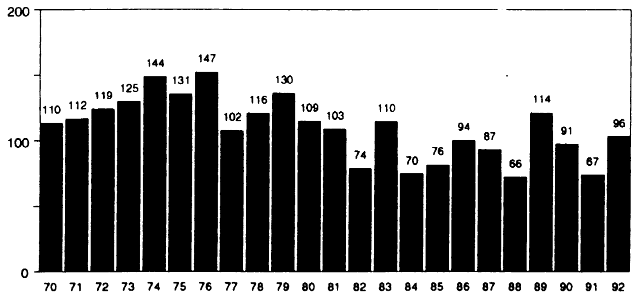


TABLE 5

PREVIOUS DECOMPRESSION ILLNESS

1988	1989	1990	1991	1992
11.6%	14.1%	12.2%1	12.8%	8.6%

TABLE 6

AGE AND SEX COMPARISON OF 1992 FATALITIES

Age	Male	Female	Total	Percent
10-19	1	1	2	2.3
20-29	13	5	18	20.5
30-39	24	4	28	31.8
40-49	22	6	28	31.8
50-59	8	2	10	11.4
60-69	1	0	1	1.1
70-79	1	0	1	1.1
Totals	**70**	**18**	**88**	**100.0**

TABLE 7

1991 CONTRIBUTING FACTORS TO DROWNING SCUBA DEATHS

Contributing Factors	Number of Divers
Insufficient air	22
Entrapment	12
Cardiovascular	4
Alcohol/drugs	4
Panic state	4
Nitrogen narcosis	3
Air embolism	7
Obesity	3
Rapid ascent	3

due to entrapment in a cave, being lost or being inattentive to the air pressure gauge. In general, the event was unexpected and the diver was unable to perform self-rescue. This happened to inexperienced as well as experienced divers. Unlike scuba injuries, scuba fatalities can be caused by a single event such as rapid ascent or diver conditions such as a panic state. The inability to adapt or respond to a sudden underwater situation may result in death.

In 1994, fifty percent of the diver deaths aged 40 or above were related to cardiovascular disease while only 5.1% of the deaths in divers under 40 were related to cardiovascular problems. In all likelihood, these individuals may have had their cardiovascular condition contribute to their death while they were doing other types of exercise. Closer health screening, however, might prevent some scuba fatalities in the older population. Individuals must take responsibility for their personal health problems. Pre-existing disease appears to make a significant contribution to scuba related deaths.

The safety standards for participating in recreational scuba diving are voluntary. These standards are reasonable and adequate safeguards to ensure diver's safety only when the diver chooses to follow them throughout their diving career. The 55 year old diver, for example, may need to be more selective in diving participation than perhaps they were when taught 30 years before. Despite the effectiveness of these guidelines, some divers will choose to dive alone and against the recommendation of safety standards. The ultimate responsibility for safety and the prevention of injury and death rests with the individual diver.

Collection and analysis of dive accident data

DAN is the only organization that collects and studies information pertaining to both fatal and non-fatal diving accidents occurring among US citizens. The annual Report of Diving Accidents and Fatalities, illustrating trends in dive accidents, diver habits and treatment effectiveness, is distributed to hyperbaric chambers in the DAN network, government agencies, dive instruction organisations, hospitals, dive equipment manufacturers, and investigative agencies free of charge. This activity comprises DAN's largest research effort for the benefit of the diving public. Collecting and analysing this information began in 1981, but has become more organised since 1986 when increased staffing and membership funds became available. In addition to the work conducted by DAN's Duke University based staff, accident data collection efforts are supported by DAN's volunteer regional referral network of 136 chambers and 520 dive medicine physicians.

The annual reports provide information that can help prevent future accidents through education of existing divers, through refinements in diver training guidelines, and through improved equipment design. This report also benefits health care workers by improving dive accident recognition and treatment. The reports, distributed free to dive instructors, hyperbaric chambers, hospitals, government agencies, instructor organisations, and equipment manufacturers, have helped to improve educational programs and shown how training and judgment are often the cause of accidents, while equipment is rarely so. The report has identified risky dive habits, pre-existing medical conditions posing special risks, and documented the effectiveness of existing treatment and first-aid measures.

Research at DAN

The goal of DAN research is to improve the safety of recreational diving by investigating the causes and mechanisms of diving injuries, therapies that are effective for their treatment, and diving guidelines which might reduce their incidence.

Other possible risk factors for decompression illness currently under review by DAN include asthma and diabetes. These common disorders have traditionally been contraindications to diving. DAN studies are attempting to quantify the risks of these conditions in order to provide the best possible advice to prospective divers. Ongoing DAN database analysis also includes a review of the results of different forms of recompression treatment for decompression illness.

While much has been learned from the diving accident database described earlier and other publications,[1-3] the critical issue of DCI risk can be addressed only with data that include DCI-free dives and accurate records of depth-time exposure. DAN is embarking on prospective laboratory and field studies to develop these data.

DAN's laboratory studies have begun a project to investigate the safety of flying after diving. The next several years will be devoted to examining the effects of pre-flight surface interval and repetitive diving on DCI risk and to the development of statistical algorithms for estimating DCI risk.

DAN's field studies will be built around the mass-produced dive computers that can record depth-time profiles. A project is under development for acquiring these dive profiles as well as data on demographics, dive conditions, and symptom occurrence. These data will be linked to the existing system for acquisition and analysis of diving injury data. Several years may be needed to develop the project before field studies can formally begin.

Education Programs

DAN holds courses annually to train physicians and health care workers in the specifics of diving medicine. In addition, one and two day courses for lay persons in dive accident first aid are taught. Physician programs are conducted for educated lay persons, for physicians, and for other health care professionals by a PhD and MD faculty. The lay courses are taught by specially trained paramedics, nurses, and MDs who provide their services without compensation. To date, twenty-four (24) dive physician courses have been taught providing dive medicine training to over 1,700 physicians and health care workers. Over 500 people have participated in DAN's one and two-day diver education programs. DAN also supports a one-year Fellowship program in Diving Medicine at Duke University Medical Center that began in 1986. This program provides training and practical experience for physicians interested in diving and hyperbaric medicine.

The DAN oxygen first aid course was unveiled in 1991. Since that time, approximately 30,000 oxygen providers, 2,200 instructors, and 500 instructor-trainers have been trained in the US and 25 foreign countries. This program is a vital link in the field management of diving casualties and the emergency medical system.

It is impossible to measure what effect these educational programs have had on the outcome of diving accidents or the improvement of diving safety. It is estimated that there are fewer misdiagnoses and less improper care administered by health care workers and lay persons as a result of DAN's dive medical training efforts, as there is no dive medicine training in most US medical schools, nursing schools, or paramedic curriculums.

Dive accident insurance

Before 1987, when DAN created the world's first affordable dive accident insurance plan, DAN on-call personnel (as well as many non-DAN dive physicians) experienced numerous delays when arranging emergency transport for injured scuba divers. The two serious conditions that affect divers; DCS and AGE, are time crucial disorders. They must be treated within hours to have a favourable prognosis. It has been documented by the US Navy that treatment within one hour of the injury results in nearly 100% recovery, but as time exceeds 24 hours, the chance of a full recovery decreases significantly.

Unfortunately, many major health care insurance companies do not cover air evacuation transport. In some cases, major medical plans do not cover hyperbaric chamber treatment when the chamber is not located in a hospital, and over 30% of the DAN network's chambers are not in a hospital. More seriously, in the past, many air evacuation transport companies would not provide transport to injured scuba divers without cash up front. The resulting delays in evacuation while physicians and family scrambled to verify cash assets and credit may have contributed to permanent, severe disabilities such as paraplegia and quadriplegia.

The delays that resulted in co-ordinating financial responsibility for evacuation not only resulted in a poorer prognosis for the injured individual, but also placed great stresses on DAN's physician volunteers. Because many chambers not located in hospitals were refused reimbursement by some major medical insurance programs, some of these facilities threatened to exclude divers from their doors.

With the advent of DAN's insurance program in 1987, guaranteeing payment to health care facilities and air ambulance companies, emergency transport became much more efficient and times were reduced. Further, many divers with minor symptoms are seeking treatment, where in the past they might not have pursued treatment. Even minor decompression cases are thought to facilitate permanent damage to the spinal cord and therefore should be treated. It is believed DAN's insurance program has significantly contributed to efforts to improve diver safety and treatment effectiveness.

Caribbean chamber assistance

Over the years, the Divers Alert Network has assisted many divers in receiving transportation and appropriate treatment to recompression facilities world-wide. DAN has been concerned that certain hyperbaric treatment facilities were at risk in popular dive destinations because of lack of funding. Because of this concern, DAN has begun a chamber assistance program, beginning with a pilot program to aid Caribbean chambers. In 1995, assistance will be extended to marginally supported chambers in other parts of the world such as the Pacific islands of Truk and Palau.

The goal of this pilot program is to provide direct financial support to recompression chambers that are involved in the treatment of recreational divers in remote dive destinations. This support may be used by the chamber to provide education to its staff, maintenance and repair of hyperbaric facilities or to purchase medical supplies. Educational courses may also be requested from DAN to help support recompression chambers and educate the local dive community. Two meetings and refresher training courses for Caribbean chamber facilities were held by DAN in 1994.

International DAN (IDAN)

International DAN comprises several independent organisations based around the world to provide emergency medical and referral services to national or continental diving communities. These local networks have pledged to uphold this mission and to operate under protocol standards agreed to by the IDAN directorate. Each IDAN member is a non-profit organization, independently administered with some support by US DAN Headquarters at Duke University Medical Center, in Durham, North Carolina. In August 1994, there were three operational IDAN branches besides the US DAN which serves North and Central America and the Caribbean:

Dan Europe (formerly International Diving Assistance, which was founded ten years ago), based in Roseto degli Abruzzi, Italy, has its central emergency hot-line in Zurich, in conjunction with an evacuation service in Milan. DAN Europe is responsible for serving European divers worldwide. Its international 24 hour emergency number is 41-1-383-1111

DAN Japan, has its central emergency hot-line in Tokyo. DAN Japan is responsible for serving divers from Japan and other Asian areas. Its international 24 hour emergency number is 81-3-3812-4999

The Diving Emergency Services (DES) operating in Australia and New Zealand are co-administered and have 24 hour emergency hot-lines in Adelaide, Australia and Auckland, New Zealand. DES Australia's international 24 hour emergency number is 61-8-373-5312. The inside Australia, toll free, number is 1-800-088-200. DES New Zealand's 24 hour emergency number is 09-445-8454.

DAN Australia is responsible for serving divers from the Australian continent and surrounding area for DAN membership services, insurance, oxygen, and other education courses and accident prevention. DAN Australia provides some support for the DES service. DAN Australia's working hours number, for administrative matters, is 03-9569-1151.

DAN Headquarters in the USA coordinates the activities between the International DAN directors and organises support services and conferences in the interest of IDAN. This includes translation of DAN materials into foreign languages, exporting training and educational materials to IDAN branches, and keeping directors apprised of new developments and changes in DAN policies. One mission of special importance is the oxygen first aid program worldwide and great strides have been made in this area. As of August, 1994, all IDAN organisations are working on an oxygen program in their respective regions of the world.

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Chris Wachholz, RN, Director of Special Projects and the liaison for DAN organisations internationally, has been employed at Divers Alert Network at Duke University Medical Centre since 1983. In that time, he has held a variety of duties including the fielding of both emergency and non-emergency medical calls, fundraising, the creation of DAN's insurance program, and general management. He was the first employee of Divers Alert Network. Chris Wachholz is a 1979 graduate of Marquette University Nursing School, a 1988 graduate of Duke University Business School, and a 1993 graduate of the Duke School of the Environment masters degree program.

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The above paper was presented at the Safe Limits Symposium held in Cairns, October 21st to 23rd 1994. It is reprinted by kind permission of the Division of Workplace Health and Safety of the Department of Employment, Vocational Education, Training and Industrial Relations of the Queensland Government, and of the author, from the symposium proceedings pages 39-51.

WESTERN AUSTRALIAN PEARL DIVERS' MODE OF DIVING

Robert Wong

Years before Haldane was working on his decompression tables with goats, in Australia, pearl divers had been diving for pearl oysters, using hard hat helmets and hand pumps, since 1884. They did not have the benefit of decompression tables to guide them, they had to work by trial and error. The cost in terms of human lives was high.

Dr Graham Blick, the District Medical Officer in Broome (1900-1908) reported in an article entitled “Divers Paralysis” in the British Medical Journal on 25 December 1909 that there were in excess of 400 divers, and they dived to depths from 7 fathoms to 20 fathoms (13-36 m); sometimes even to 25 fathoms (46 m). Spinal cord decompression sickness (DCS) was so common that no diver would consider his outfit complete without a soft catheter.

In 1912, hand pumps were replaced by engine driven pumps and diving to greater depths was achieved resulting in more fatalities. In 1913, there were 29 deaths, and 1914, thirty three deaths from diving (Table 1). CE Heinke & Co, who supplied the diving equipment to the pearlers, donated a recompression chamber (RCC) to Broome for treatment of paralysed divers in 1913.

From those grim days, the pearl divers, out of necessity and self-preservation, evolved their own dive table; handed down over the years and refined in the process. The profiles used were not based on any scientific knowledge that they had, but the profiles worked for the pearl divers in that they contained the incidence of DCS to an acceptable level.

For economic reasons, the aim was to maximise the bottom time in order to harvest as many oysters as possible. The old Japanese divers used to do 8 dives a day with 30 minutes on the bottom, not bottom time! They used to ascend slowly and do a decompression stop. On the last dive of the day, they would “hang off’ for an hour or so before surfacing. Even then, they would sit very still for another hour before they would dare to move. The surface interval was about 10 minutes, this was the time taken for the pearling vessel to turn around for another drift. The current pearl divers’ profiles are based on this well tried “recipe”.

In 1971, hookah equipment was introduced into Broome after news of the successes of the abalone divers in NSW. The initial first 3 months was unsuccessful, the catch rate was only about 16% of the standard hard hat diving. Eventually a system of shot lines and drag ropes was devised, and by 1975, the last hard hat diver had retired.

In 1983, pure oxygen breathing was introduced for use in decompression by some of the pearl divers.

In late 1990, under the umbrella of the Pearl Producers Association Inc. (PPA), the 13 pearling companies agreed to dive to a set of profiles so these could be studied.

With the present method of working the boats have a hydraulic boom on either side near the stern. Two divers work each side of the boat. A shot line, weighted at the expected depth to be close to the bottom, goes down from the boom for each diver. This rope hangs almost vertically. A large catch bag is attached to the line near the weight with an inflatable bag to take it to the surface when full. The diver works from an extension of the weighted line (work line) which trails behind the weight. A knot is in the line approximately 3 m from the end to warn the diver that he is about to run out of line. The diver holds the line with one hand and picks up pearl oysters with the other putting it in a bag worn round his neck. When the bag is full he pulls himself up the line and empties it into the larger bag, then returns to shell gathering. When the large bag is full it is sent up to the surface using the inflatable bag. This set up is shown in Figs 1 (from above) and 2 (from the side).

Besides the hookah gear each diver wears a small cylinder of air with its own regulator (bail out or pony bottle) so that he has an air supply for decompression if the main hookah supply should fail for any reason.

In 1991, a RCC was purchased by the PPA and donated to the WA Department of Health and was installed

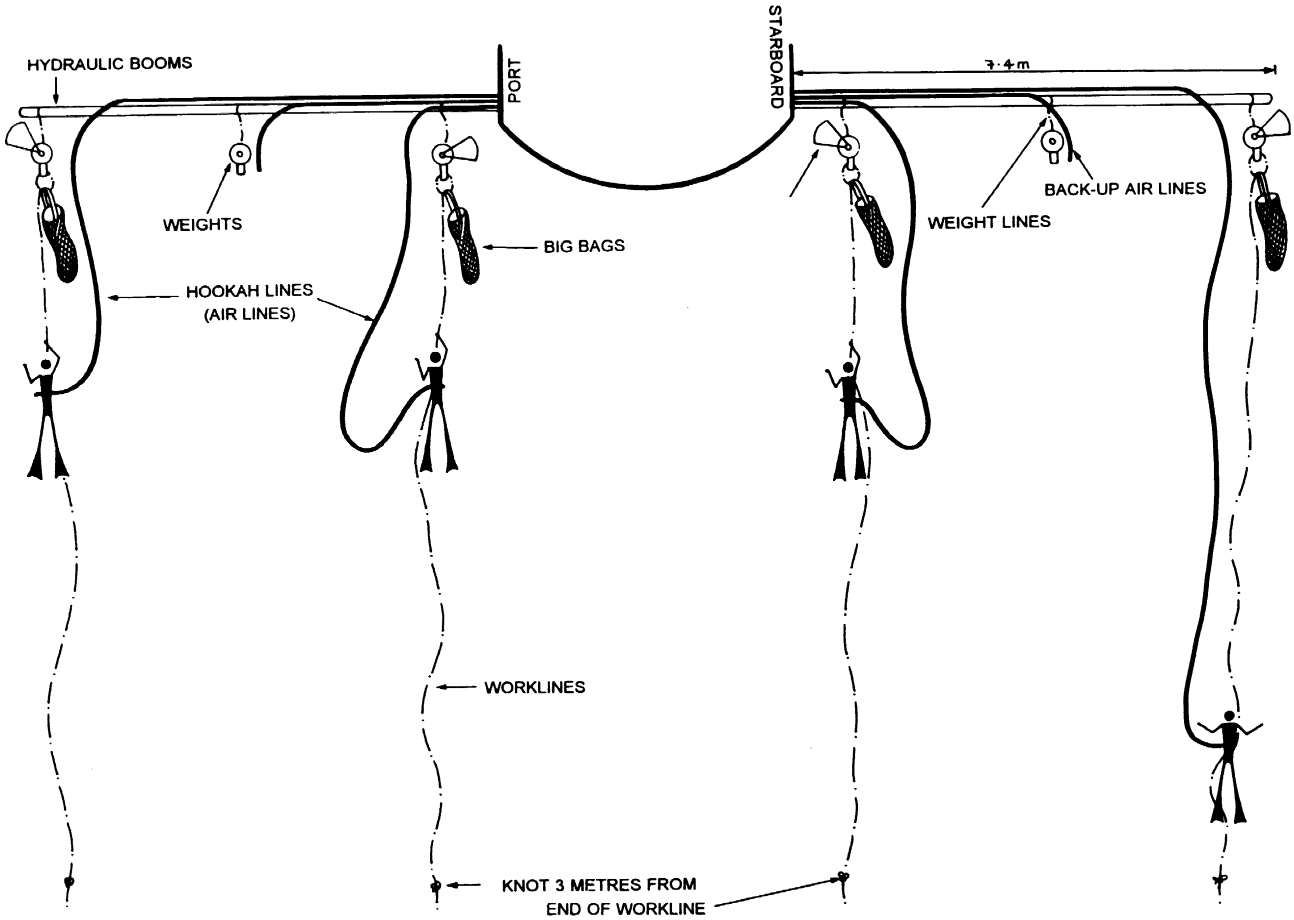
TABLE 1

FATALATIES IN WESTERN AUSTRALIAN PEARL DIVERS WORKING OUT OF BROOME 1910-1920

Year	Deaths
1910	11
1911	10
1912	9
1913	29
1914	33
1915	21
1916	19
1917	12
1918	1
1919	3
1920	4

FIGURE 1

OVERHEAD VIEW OF PEARL DIVING OPERATION



in Broome District Hospital. Towards the end of 1991, Doppler ultrasound studies were begun at sea to record the bubble scores of the divers fishing for oysters.

In 1992, the profiles were studied in the RCC in strict accordance with the profiles printed in the Code of Practice of the PPA Inc. Any dive profile which scored higher than Grade II bubble scores were considered stressful and were modified by either decreasing the bottom time, increasing the decompression time, or decreasing the number of dives per day. The surface interval is not usually interfered with because it is the time that takes a fishing boat to turn around for another drift. After the RCC trials, most of the profiles have been modified.

Figure 3 and table 2 shows the number of dives performed at each depth (from <11 msw to 35 msw) from 1991-October 1994. In 1991 there were 30,095 dives resulting in 4 cases of musculo-skeletal DCS. The PPA Profiles start from 11 msw with 2 msw increments, up to a maximum of 35 msw.

TABLE 2

DEPTHS AND NUMBER OF DIVES 1991 TO OCTOBER 1994

Depth	**Number of dives**			
	1991	**1992**	**1993**	**1994**
<11	5,400	7,075	5,269	8,742
<13	5,189	6,821	4,429	5,226
<15	4,013	4,373	2,470	2,274
<17	3,898	3,168	1,738	1,080
<19	5,366	3,835	2,624	1,320
<21	3,682	2,856	2,189	1,212
<23	989	547	621	534
<25	38	35	12	48
<27	8	220	88	0
<29	101	269	316	0
<31	537	118	332	0
<33	861	455	764	0
<35	320	323	600	0
Totals	**30,402**	**30,095**	**21,452**	**20,436**

FIGURE 2

SIDE VIEW OF PEARL DIVING OPERATION.

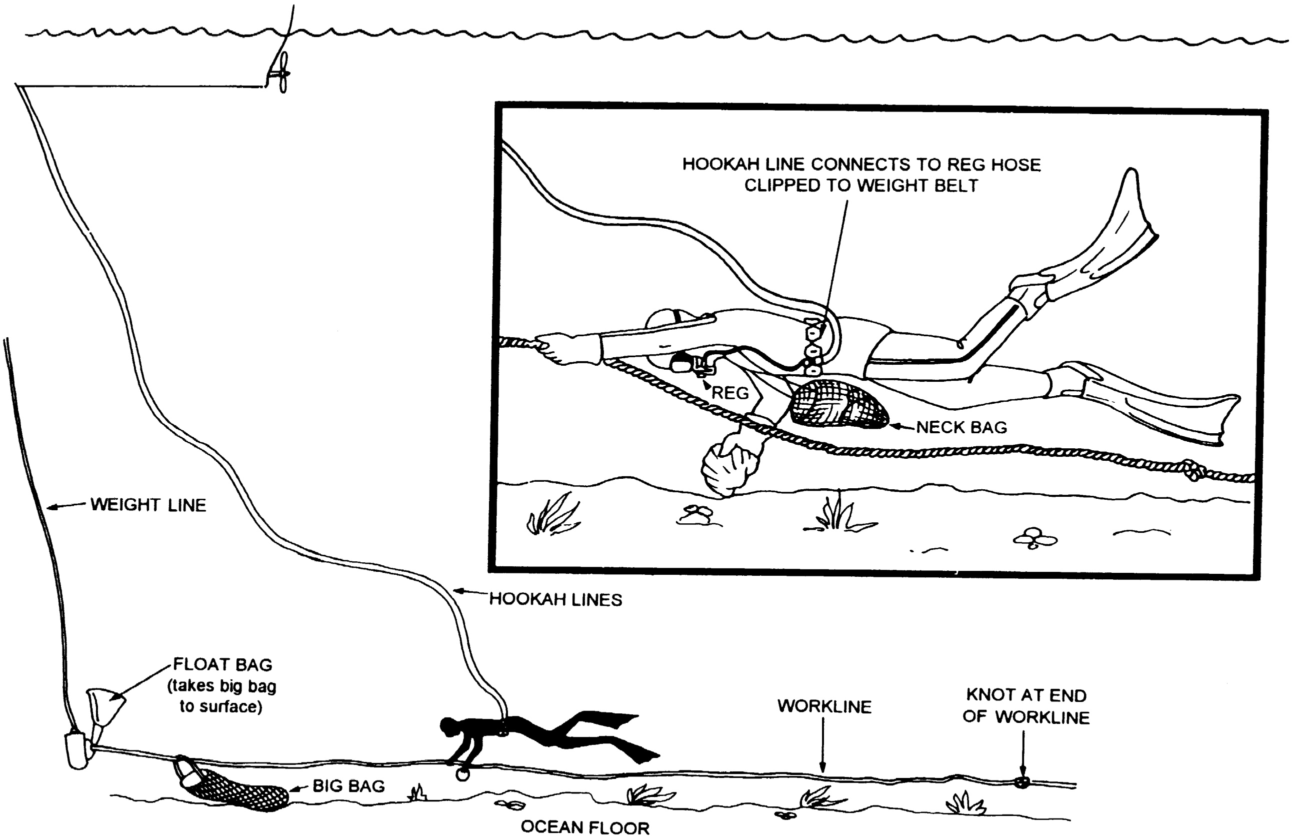
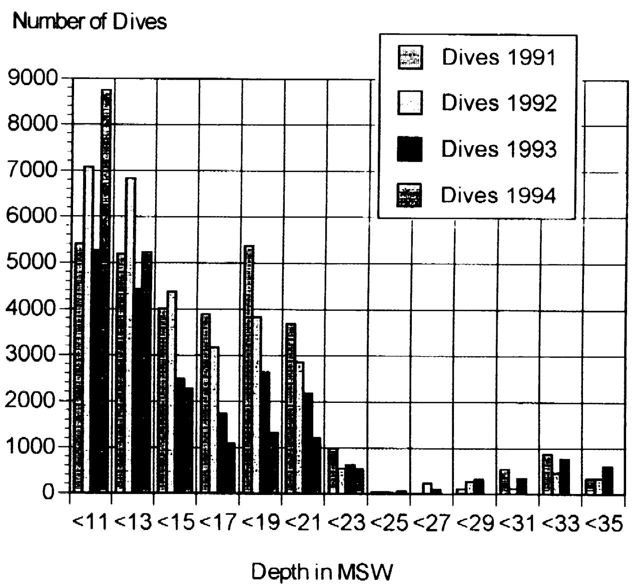


FIGURE 3

NUMBER OF DIVES AND DEPTHS 191 TO OCTOBER 1994



The main aim of the PPA profiles is to achieve the maximum time in a 12 hour day-light working day, from about 0600 to 1800.

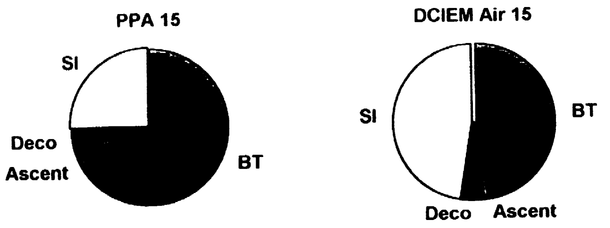
In the shallow depths, they try to achieve 500 minutes of bottom time (BT) for the day e.g. for 11 msw, they use a BT of 90 minutes per dive; for 13 msw, they use a BT of 60 minutes per dive. With deeper depths, they reduce the bottom time of each dive as well as the number of dives for the day, such that at 35 msw, they dive for a bottom time of 25 minutes and perform only 4 dives for the day. As for surface intervals, for dives up to 23 msw depth, the surface interval is fixed at 20 minutes. For deeper depths, the surface interval is increased by extra 10 minutes after each dive e.g. for 35 msw dive, the surface intervals are 80, 90 and 100 minutes. The ascent rate is fixed at 3 msw/minute this is achieved by ascending slowly hand over hand on the shot rope. At the end of the day, regardless of depths of the dive, all divers do a compulsory decompression stop.

Figure 4 compares the PPA profiles with the DCIEM tables (15 msw air; 21 msw oxygen and 33 msw oxygen decompression tables). It can be seen that the PPA profiles have longer bottom times; the combined ascent time and

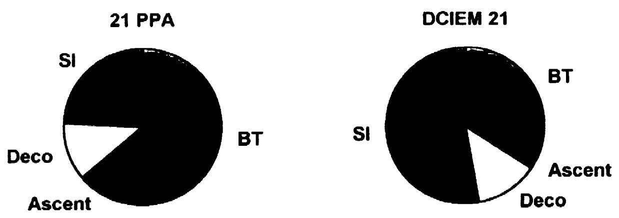
FIGURE 4

COMPARISON OF PPA AND DCIEM PROFILES

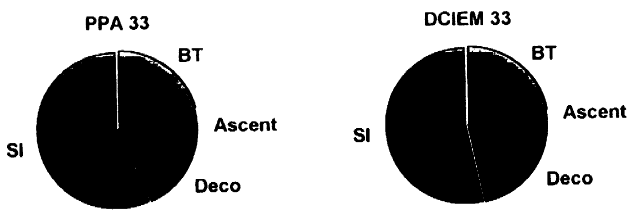
The areas in each pie graph represent the percentage of the total working time



15 msw profiles
PPA compared with DCIEM Standard Air
Bottom Time PPA 450 minutes, DCIEM 315 minutes
Total Time PPA 710 minutes, DCIEM 672 minutes



21 msw profiles
PPA compared with DCIEM oxygen decompression
Bottom Time PPA 360 minutes, DCIEM 240 minutes
Total Time PPA 663 minutes, DCIEM 738 minutes



33 msw profiles
PPA compared with DCIEM oxygen decompression
Bottom Time PPA 125 minutes, DCIEM 125 minutes
Total Time PPA 700 minutes, DClEM 562 minutes

the decompression time of the PPA profiles are similar to those of the DCIEM. The major deviation is the much shorter surface interval of the PPA profiles. It is also of note that the PPA and the DCIEM profiles tend to converge at the 33 msw depth, where the 2 profiles are very similar.

It is superfluous to state that the safety of a set of decompression tables depends not only on the incidence of decompression illness (DCI), but also on the manifestations of DCI. Since the modifications of the PPA Profiles at the end of 1991, the incidence of DCI had been low:

1992	- 4 cases, all musculo-skeletal DCI
1993	- 3 cases, all musculo-skeletal DCI
1994 (to October)	- 0 cases.

Discussion

As is common in the Northern parts of Australia, tidal variation is large, hence the divers only dive during the neap tides.

Despite the multi-day diving of up to 7 to 8 consecutive days during the neap tides, repetitive dives of up to 10 dives a day (in shallow waters and reducing to 4 dives a day at 35 msw) and they frequently dive from shallow to deep waters in contravention to conventional wisdom, because of the tidal variations. The incidence of DCI in the pearl divers since 1992 has been less than 0.01%.

Since the introduction of oxygen in decompression, the pearl divers have not recorded a single case of oxygen toxicity.

One must emphasise that the PPA profiles are all "dived profiles" and not mathematical calculations and extrapolations.

The reasons for their relative safety despite their differences from the conventional profiles might be due to the following four factors:

Slow rate of ascent

The pearl divers ascend at 3 msw/minute as opposed to 18 msw/minute in the standard decompression tables.

Zannini reported that the Italian commercial divers now routinely use a 10 m/minute rate of ascent and recorded no incidence of DCS over 24 ,000 dives at depths ranging from 10-50 msw.

Mano demonstrated with his agar gel experiments that as ascent rate decreases, the number of bubbles also decreases. Mano indicated that the optimum rate of ascent was 9 m/minute.

Daniels has calculated that if the rate of ascent was to decrease to some 25 times in a saturation dive, then bubble formation could be avoided.

In accordance with the DCIEM Decompression Manual, if an ascent rate is too slow, then a penalty is added to the dive as extra bottom time. This is not done in the PPA profiles.

It appears that this slow rate of ascent has not been adequately studied, and the pearl divers, by trial and error, having attempted various rates of ascent, from fast to very slow, managed to "discover" a safe, workable ascent rate for themselves.

The current available data on ascent rates indicated that the slower ascent rates decrease the likelihood of bubble formation and that a shallow stop for a short period significantly decreases the risk of pressure related injury.

In-water oxygen decompression

There are well known decompression tables which employ oxygen in decompression.

Oxygen decompression decreases decompression time by 50% for 15 msw dives and 30% for 60 msw dives (Comex tables); and it has been reported that the incidence of DCS with 0_2 decompression was 2-3 times lower than with air decompression for dives of the same depth and bottom time.

Oxygen decompression was used in the excavation of a stone age shipwreck with dives to depths between 50-60 msw. Of the 7,500 air dives, there were 3 cases of DCS and no incidence of oxygen toxicity was encountered.

Suitable inter-dive surface interval

The actual surface interval for complete nitrogen clearance is unknown. The theoretical intervals from various decompression tables vary from 6 hours (Rogers), 12 hours (USN) to 18 hours (DCIEM). As the calculation of repetitive dives is dependent on the residual nitrogen load, one could hypothesise that with the appropriate rate of ascent and suitable decompression stops, the elimination of inert gas could be maximised and bubble formation minimised.

It is known that dissolved and free gases do not behave in the same manner and bubble formation is initiated by micronuclei. It was noted that bubbles were more numerous during the first ascent than the second during saturation dives, it has been postulated that this might be due to nuclei being used up and insufficient time for them to regenerate. Therefore, a suitable interdive interval may bestow some benefit to repetitive dives by a reduction in the number of bubbles. Repetitive dives might consume such micronuclei such that subsequent dives are made more safe by having less number of micronuclei to form bubbles.

In the Doppler studies, bubble grades tend to peak at or around 2 hours after surfacing. If, however, the surface interval was to decrease, the bubbles which were formed might be forced back into solution.

It has also long been assumed that "yo-yo" diving predisposes to DCI. However, a recent study refuted this. Although, Parker et al. using the USN 1993 model suggest that DCI risk of yo-yo diving might be higher if a large number of ascents (>10) were made. Perhaps the rate of ascent might play a major part, which has not yet been studied.

In the past the assumption has been made that when the surface interval is too short the bubbles which were formed on decompression could cross the pulmonary circulation, on recompression, and lead to serious forms of DCI. This has not been observed in the pearl divers.

Adaptation to decompression.

Adaptation is unlikely, as the pearl divers dive from 4 to 8 consecutive days, then have a break of 7 to 8 days. Also adaptation, in tunnel workers, was specific for each pressure, whereas, the pearl divers diving depths vary according to where the pearls are found, irrespective of depths.

In the analysis of the DCI cases, they seemed to occur at a random basis. It has to be said that at the beginning of the diving season, all the divers take particular care in avoiding DCI, as they seem to be aware that they are more prone to DCI after a lay off period.

The long term health effects of this mode of diving are not known. However, all the divers are obliged to have annual diving medical examination in accordance with the AS2299, including skeletal surveys. No abnormalities have been detected at this stage ()ctober 1994).

Conclusion

Compared to conventional decompression tables, at first glance, the PPA profiles appear to be grossly inadequate in their decompression stops (including oxygen decompression), and surface intervals for their repetitive and multi-day diving.

However, this study has shown the profiles to be safe. The incidence of DCI has been less than 0.01%.

It appears that the most important contribution to the success of the PPA profiles is the slow ascent rate at 3 msw/minute. The pearl divers mode of diving would not suit other divers, but the profiles have made great contribution towards diving safety in repetitive and multi-day diving.

The profiles are being continuously assessed and evaluated.

Dr Robert M Wong is a Consultant Anaesthetist at the Royal Perth Hospital, Western Australia, and for the Royal Australian Navy. He is also Consultant in Underwater Medicine at the Royal Perth Hospital, to the Royal Australian Navy, the Western Australian Department of Health (Kimberley Region) and the Pearl Producers Association Inc.

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The above paper was presented at the Safe Limits Symposium held in Cairns, October 21st to 23rd 1994. It is reprinted, with some additions, by kind permission of the Division of Workplace Health and Safety of the Department of Employment, Vocational Education, Training and Industrial Relations of the Queensland Government, and of the author, from the symposium proceedings pages 67-72.

AN EXCELLENT SAFETY RECORD DESPITE THE RISKS

Rod Punshon

Introduction

PRO DIVE Cairns is one of the largest diver training centres in the world. We currently train, under the PADI system, approximately 4,000 divers each year. This number is made up of predominantly open water certifications (80%) with the balance being advanced or higher level training.

PRO DIVE Cairns has been in operation since September 1983 and has trained 35,000 (thirty-five thousand) divers to date. In addition to diver training, PRO DIVE also carry certified divers on their three day/two night live-aboard trips, approximately 1,000 per annum.

In conducting these activities, we can accurately calculate the number of dives carried out each year from our vessels as follows:

1 Divers under training, 12,800 per annum
2 Dives conducted by newly certified divers whilst on their certification trip, 16,000 per annum
3 Divers engaged in higher level training, 7,200 dives per annum
4 Certified dives (non-training), 10,000 dives per annum
5. Staff dives (Instructors), 5,000 dives per annum

Therefore, the total non-staff dives equal 46,000 and total staff dives equal 5,000, totalling 51,000 dives conducted annually, as multiple dives in multiple days, from our two vessels.

Dive location

Since our inception, all of our diving has been conducted at the same three reef locations on the Cairns outer reef. Common influencing factors at these three sites are as follows:

a Open water training dives are conducted in a maximum depth of 18 m, but all skills training is conducted between 8 and 12 m. Non-training and higher level certification dives are to maximum depth of 30 m (excluding deep dive training).
b Visibility is normally 10 - 30 m.
c All dives are conducted where current is less than half a knot.
d Temperature variates between 22 and 29°C in Cairns.
e All dives are conducted on the protected side of the reef where surface conditions are negligible even in reasonably adverse weather.
f All moorings have been strategically located to minimise the need for prolonged swims to the dive site.
g All equipment supplied is current model and undergoes a quarterly preventative maintenance program. 5 mm wetsuits are provided to all divers as part of their equipment.

Decompression illness

We have broken down our reporting of incidents into a six and a five year period, 1983 to 1989 and 1990 onward. Our reason for this was that in 1990, our Company Code of Practice and operational procedures was revised in light of current industry knowledge and practice.

In the period 1983 to 1989, we recorded 21 incidents of decompression illness (DCI) requiring treatment at the chamber in Townsville, which in those days was located at the Australian Institute of Marine Science (AIMS). Thirteen of these required evacuation, the remaining eight presented after completion of the trip and the vessel's return to Cairns, some time after their last dive.

Reports from the chamber indicated that, with few exceptions, these incidents were of a minor nature. Of the 21 cases, three were suffered by staff members, giving an incidence of three cases per 30,000 staff dives, or one per 10,000.

There were eighteen incidents in non-staff divers, giving a ratio of eighteen incidents in 276,000 dives or one per 15,300 dives.

In the period 1990 to date, we have had four cases of DCI, all requiring evacuation from Cairns. These were all non-staff injuries. In this period staff conducted 25,000 dives. It should be noted however, that our instructors were, until January 1993, doing as many as 50 ascents on any one three day trip and most of these were in rapid succession. After January 1993, the number has been reduced to a maximum of twenty ascents on any three day trip. These ascents are generally conducted in eight to ten m of water.

The four non-staff injuries were incurred during a total of 230,000 dives, giving a ratio of one per 57,500, an improvement of nearly 400%.

We can attribute this improvement in results to:

1 Strict adherence to "deepest dive first". This policy is enforced by a mandatory break of a minimum of 12 hours out of the water for any deviation from this basic policy.
2 A limiting of maximum depth for certified divers, unless under direct supervision or training, to 30 m.
3 Limiting alcohol intake and encouraging more rest. We actively discourage partying on board during trips.
4 We now calculate and check all dive profiles and ensure compliance with "no decompression'' table limits on each dive.
5 Any accidental entry into decompression is penalised by a minimum of six hours out of the water, depending on the severity.

In summary, we feel that the improved basic safe diving principles we have introduced in the last five years have significantly improved our safety record.

While we are not qualified, and have no intention of trying, to draw medical conclusions from these limited statistics, we feel that it is vitally important to put these statistics forward as actual data for consideration and evaluation by this group.

Mr Rod Punshon is director of a large recreational diving company in Cairns, North Queensland and is a member of the Diving Industry Workplace Health and Safety Committee. His address is PO Box 5551, Cairns, Queensland 4870, Australia.

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A CASE FOR SAFETY

Phil Percival

Australian regulatory structure

Australian offshore production operations are at present conducted in the States of Western Australia and Victoria, and in the Northern Territory. Those operations located within State waters are under State jurisdiction, whilst operations in Federal waters, generally beyond 3 nautical miles from land, are covered by Federal jurisdiction but controlled by the adjacent State authorities on behalf of the Federal Government. The effect of this arrangement is to provide uniform offshore petroleum legislation throughout Australia.

Offshore facilities

Australia has a wide range of offshore production facilities which include Northern North Sea style platforms such as North Rankin A and Goodwyn A , smaller Southern Gasfields type platforms in the Bass Strait and floating production and storage vessels like those in the Timor Sea. There are also a variety of unmanned platforms and jack-up rigs serving as production platforms. As the development trends take us into deeper waters, new and cost effective methods of hydrocarbons recovery will be found. The use of concrete platforms has already been introduced in the Bass Strait, and is being examined in Western Australia. Large gas fields are awaiting favourable economic conditions for further development on the North West Shelf.

Piper Alpha, a catalyst for change

The Piper Alpha offshore production platform disaster in the North Sea was a catalyst for a significant rethink on safety in the offshore petroleum environment. Lord Cullen's UK public enquiry made 106 recommendations directed at the improvement of safety, and many of these were aimed at management of safety rather than hardware. It was Lord Cullen's view that operators appeared to have safety systems in place but that the management of them was lacking. A quick review of Piper Alpha will help us to focus on this view.

At about 10 p.m. on 6 July 1988 an explosion occurred in the gas compression module on the Piper Alpha platform, 176 km north east of Aberdeen. This initial explosion put the main control room and main power supplies out of action and caused extensive damage to hydrocarbon processing equipment. It was followed immediately by a large fire in the oil separation module, which gave rise to a massive plume of black smoke which engulfed the north end of the platform. This fire was fed by oil from the platform and a leak in the main oil line to the shore, to which the pipelines from the Claymore and Tartan platforms were connected.

At about 10.10 p.m. there was a second major explosion which caused a massive intensification of the fire. This was due to the rupture of the riser on the gas pipeline from Tartan. Ruptures of risers on the gas disposal pipeline to Frigg and the gas pipeline connecting Piper with Claymore further intensified the fire on Piper.

There is evidence that the emergency shutdown system was activated and emergency shutdown valves on the gas pipeline risers probably closed, although extended flaring pointed to the failure of a valve on the Claymore riser to close fully. The other emergency systems on the platform failed immediately or within a short period of the initial explosion. In particular, the fire water system was rendered inoperative either due to physical damage or loss of power. At the time of the initial explosion the diesel fire pumps could not be started remotely as they were in manual mode.

The platform structure collapsed as a result of the explosions, initially forcing men to jump into the sea out of shelter on the pipe deck. The east quarters module lost its structural support and tipped to the west, crushing the west quarters module, and then tipped northwards into the sea. Between 10.30 p.m. and 12.15 am. the centre of the platform collapsed. The risers from the gas pipelines and the main oil pipeline were torn apart. The north side of the platform slowly collapsed until the additional accommodation module slipped into the water.

There were 226 men on the platform at the time. Sixty two were on nightshift duty while the remainder were in the accommodation. The system for control in the event of a major emergency was rendered almost entirely inoperative, smoke and flames outside the accommodation made evacuation by helicopter or lifeboat impossible.

Diving personnel on duty escaped to the sea along with other personnel on duty at the northern end and the lower levels of the platform. Other survivors who were on duty made their way to the accommodation, and a large number of men congregated near the galley on the top level of the accommodation. Conditions there were tolerable at first, but deteriorated greatly owing to the entry of smoke. A number of personnel, including 28 survivors, reached the sea by use of ropes and hoses or by jumping off the platform at various levels. At no stage was there a systematic attempt to lead men to escape from the accommodation.

To remain in the accommodation ultimately meant certain death. Sixty one persons from Piper survived. Thirty nine had been on night shift and 22 had been off duty. One hundered and thirty five bodies of the 165 persons who died were later recovered. The principal cause of death in 109 cases (including 79 recovered from the accommodation) was inhalation of smoke. Fourteen apparently died in an attempt to escape from the platform. Few died of burns. Two members of the crew of a fast rescue craft were also killed.

Piper Alpha had a permit to work system but it was not being used correctly, there were fire-pumps but they were isolated from automatic start-up, there were emergency procedures but they did not work and there was management but it did not function effectively. To cap it off there was a regulatory authority that did not have the incentive to effectively administer offshore safety.

Lord Cullen recommended that offshore petroleum operators should be required to demonstrate their commitment to safety through the preparation of a Safety Case. He considered that the responsibility for offshore safety should be put more clearly on the companies rather than the regulator.

In Australia the Commonwealth and State governments, industry and unions formed a tripartite committee known as COSOP to monitor the outcome of the UK enquiry, and to assess the applicability of the Cullen recommendations to the Australian offshore industry. The Safety Case concept was unanimously adopted and has been legislated in Australia for new offshore installations. Similar requirements for existing installations and MODUs (mobile off-shore drilling units) will be effective no later than 1st July 1996.

The Safety Case

So what is a Safety Case and what implications does it have for the diving industry?

A Safety Case is the formal means by which an operator demonstrates to the regulator that he has identified all of the major hazards that could potentially affect his installation, that he has taken steps to eliminate or mitigate the risk of those hazards becoming reality, and has a safety management system which is designed to deal with any residual risk, including ongoing identification of new hazards.

The Safety Case is a living document that is conceived at design, has a life cycle through construction, installation and operation, and terminates after abandonment.

Let us us look at the essential elements of a Safety Case. There are three key elements:-

General description;
Formal safety assessment; and
Safety management system.

The general description is a comprehensive document with supporting drawings covering installation location, environmental conditions, design basis, codes and standards, etc. Enough to give the assessors an understanding of the total project.

Formal safety assessment is a methodical identification of hazards, an assessment of consequences and an analysis of probabilities. It may be done qualitatively, quantitatively or both! It is used to demonstrate to the regulator and to the operator that risks have been reduced to as low as reasonably practicable. This may be done by some form of cost benefit analysis.

In layman's terms the formal safety assessment will tell us what could go wrong, why it will not go wrong and if it does go wrong what will be done to minimise loss.

The third element of the Safety Case is the safety management system. This is the system that will ensure that residual risk, that is the risk that cannot be engineered out, will be managed in a way that reduces risk to personnel to a level that is as low as is reasonably practicable or ALARP.

A typical safety management system contains these sub-elements and most of you will be familiar with them:-

Safety policy and objectives
Organisation and responsibilities
Procedures for design, construction, modification, maintenance and operations
Management of contractors
Employee involvement
Personnel standards, recruitment and training
Emergency response system
Incident reporting and investigation
Performance review and audit

Practical implications

One of the major practical implications of the new regime is to move away from prescriptive legislation towards objective setting legislation. The roles of the regulator will be to work with the operators in preparing their Safety Cases, assess Safety Cases, and audit Safety Cases. From a regulatory point of view it is seen as consultative until the Safety Case is approved, and inspectorial after approval. The significant difference being a move towards self-regulation and the removal of constraints that impede the application of technological change to design and operation.

Another important practical implication is the tripartite process. Government is seeking to ensure that employees are participating effectively in the new regime. Participation does not just mean information giving, it also means active involvement in identifying occupational health and safety risks, and in the implementation of control measures to reduce those risks to a reasonably practicable level.

In summary those things that were previously taken for granted are now required to be demonstrated to employers, employees and government. Note the word "demonstrated". Not described but demonstrated. This means that those operations, maintenance, safety and emergency procedures manuals that were previously gathering dust on the shelves must now be actively implemented, monitored, audited and improved in a quality managed way. It also means that design engineers, who previously referred to codes and standards, can to a certain extent use a more entrepreneurial approach but will be held accountable for not just the end results, but also for the ongoing results.

In respect to the diving industry the major impact comes from the interface between diving/marine and petroleum operations in areas such as supply vessels, standby craft, construction barges, diving support vessels, MODUs, FPSOs (floating processing, storage and off-loading facilities) and shuttle tankers. Where these vessels are operating on petroleum sites, the title holder is responsible for including their operational safety interfaces in his Safety Case. As an example, if a Diving Support Vessel (DSV) is to be located alongside a production platform for a work program then new potential hazards are being introduced, and more people are being exposed to them. This scenario will require the diving/marine operator to prepare a vessel/diving Safety Case/Report, and the production operator to prepare a bridging document which links the two operations together and demonstrates that risk has been reduced to as low as reasonably practicable.

The way ahead

Increasing offshore oil and gas production levels present new challenges to our industry. Let us examine some of these using the benefits of experience gained in other parts of the world where similar growth has taken place.

First the aviation industry. It is well known that helicopter travel represents a significant proportion of risk to those who travel offshore. In the United Kingdom this has been learned from bitter experience with helicopter accidents claiming many lives. Here we have been more fortunate but nevertheless lives have been lost. Our superior weather conditions and relatively short runs reduce the risk significantly. However this tranquil picture is sometimes broken by the need for mass evacuation during cyclone conditions. This is the time when the operation is most at risk. Fast turnarounds, full payloads, deteriorating weather conditions and the absence of marine rescue craft as they head for shelter.

Another potential risk that can creep up slowly on the aviation industry is gradual change brought about through development. More flights, platforms further away from shore, more variety in heli-decks and operational procedures. To overcome this problem area the WA Department is seeking to work with the Civil Aviation Authority in conducting a joint audit of all offshore helicopter operations in the second half of this year.

A second area that needs to keep pace with offshore growth is the preparedness of State emergency services to deal with a major offshore emergency. In Western Australia arrangements for State emergency response plans are the responsibility of the Police Commissioner through the State Emergency Management Advisory Committee (SEMAC). This Committee recently approved the review and overhaul of State plans for the offshore industry taking into account new and planned facilities, national resources and stake holders. Mutual aid is also being encouraged as an essential ingredient to robust major emergency response planning similar to the North Sea sector clubs. It must, of course, be remembered that the operator is always responsible for the safety of his personnel until they are transferred to a "place of safety". A place of safety in this context means a place where normal services, including medical attention, are restored.

Diving operations represent another significant risk area and are a major challenge to industry. Currently diving is strictly regulated through prescriptive directions issued by the Department under the Petroleum (Submerged Lands) Act. In keeping with the new Safety Case regime there is a requirement to replace prescriptive regulations with objective setting regulations. The challenge here is for the diving industry to demonstrate that it is capable of self-regulation through the introduction of management systems that set out to continuously improve safety.

In Australia, and in Western Australia particularly, we have an enormous future in the offshore hydrocarbons industry. Along with an increase in production must come an increase in professionalism at every level and across the spectrum of the petroleum, aviation, diving, maritime and offshore construction industries. There is still something of the Wild West out there which, while it has been admirable in forming part of our special pioneering history, is not applicable to 21st century technology. Today we are striving to "manage risks" not "take risks'".

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