13 Vann RD and Thalmann ED. Decompression physiology and practice. In: Bennett PB and Elliott DH Eds. *The physiology and medicine of diving, 4th Edition.* London: Saunders, 1993; 376-432
14 Workman RD. *Calculation of decompression schedules in nitrogen-oxygen and helium-oxygen dives*. Research Report 6-65. Washington DC: Experimental Diving Unit, 1965
15 Nishi RY. Doppler and ultrasonic bubble detection. In: Bennett PB and Elliott DH Eds. *The physiology and medicine of diving, 4th Edition.* London: Saunders, 1993; 433-452
16 Lambertson CJ and Idicula J. A new gas lesion in man induced by isobaric gas counterdiffusion. *J Appl Physiol* 1975; 39: 434-443
17 Hyldegaard O and Madsen J. Influence of heliox, oxygen and N_2O-O_2 breathing on N_2 bubbles in adipose tissue. *Undersea Biomed Res* 1989; 16: 185-194
18 Hyldegaard O, Moller M and Madsen J. Effect of He-O_2, O_2 and N_2O-O_2 breathing on injected bubbles in spinal white matter. *Undersea Biomed Re*s 1991; 18: 361-371
19 Acott CJ and Gorman DF. Decompression illness and nitrous oxide anaesthesia in a sports diver. *Anaesth Intens Care* 1992; 20(2): 249

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

This paper was first published in Anaesthesia and Intensive Care (1995; 23: 187-190) and is reprinted by kind permission of the Editor.

Dr Des Gorman, BSc, MB ChB, FACOM, FAFOM, Dip DHM, PhD, is Director of Medical Services, Royal New Zealand Navy, Consultant, Royal Adelaide Hospital, Consultant, Royal Australian Navy and Senior-Lecturer, University of Adelaide.

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

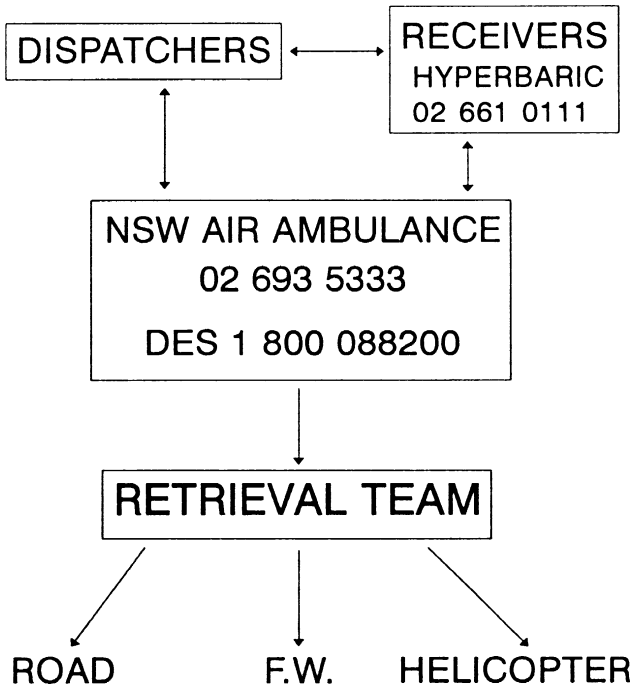

Figure 1. Schematic view of the NSW retrieval system and access numbers into the communication loop.

(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

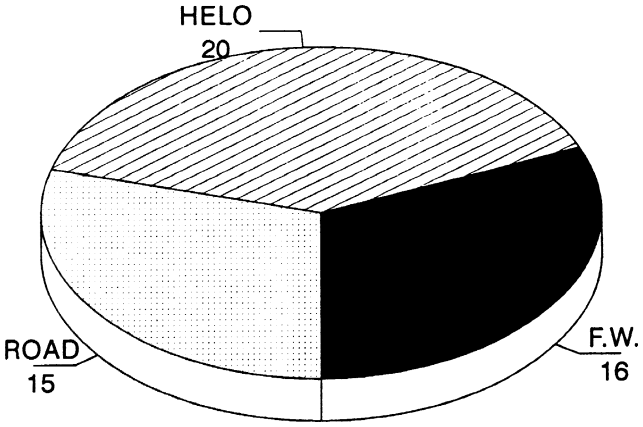

Figure 2. Mode of retrieval.

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

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

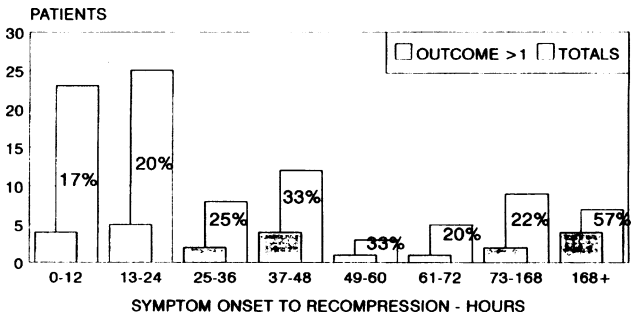

Figure 3. Outcome and treatment delay in 107 patients. Percentages show the proportion of each group with an outcome score of > 1.

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

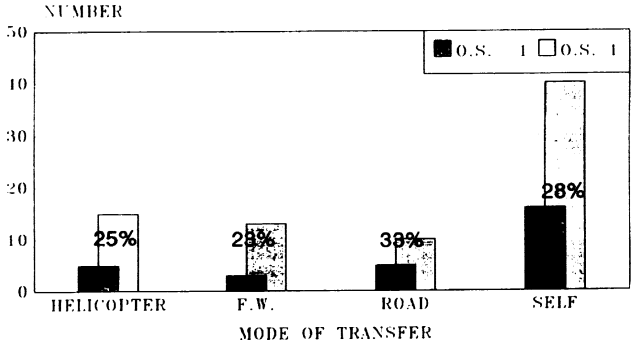

Figure 4. Outcome and transport mode in 107 patients. Percentages show the proportion of each group with an outcome score of > 1.

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

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.

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.

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.

References

1 Bosshard RG, Yeo JD, Howe P and Ambrose G. Mechanical vibration and noise during patient transport, a comparative study. *Australian Biomed Engineering J* 1981; 2: 97-102

2 Gorman D and Harden M. Outcome after treatment for decompression illnesses in Australasia. *SPUMS J* 1993; 23 (3): 165-168

Dr Mike Bennett MB BS, DA(Eng.), FFARCSI, is Medical Director, Hyperbaric Unit, The Prince Henry Hospital, Sydney, New South Wales, Australia.

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