For severe disease rapid transport to a hyperbaric facility, after stabilisation, is indicated. This is even more important when symptoms of DCI appear early. New Zealand's geography means dive locations are often remote and separated from Auckland by mountains. Helicopters, being able to keep below 300 m, and some fixed wing aircraft, which can be pressurised to ground level, may have advantages over !and transport by car or ambulance.

In the early 1980s in the Northland area we instituted a local service based on St John's Ambulance notification. Now the Westpac helicopter service, which is co-ordinated from Auckland, has replaced the original scheme. The main disadvantage is the lack, in Auckland, of local knowledge of the geography. Paramedics now attend emergencies and diving doctors are no longer used. In some cases helicopters are, in fact, a slow option because of delays in reaching the patient when the helicopter is already in use elsewhere,

Helicopters enable access to remote areas, Northland is now being serviced from Auckland by the Westpac Squirrel or from Whangarei by the Northland Emergency Services Trust (supported by Northpower) using a Kawasaki BK117 helicopter. These are expensive, limited for space, but well equipped with resuscitation gear. If the patient is acutely unwell and unstable, helicopters can be a less safe option than an ambulance which has room for on-going resuscitation and treatment by a doctor.

The following case illustrates some of the problems in Northland.

Case report

In March 1984 a 20 year old man, an experienced diver, entered the water at 0930 off the Cavalli Islands, about 225 km, as the crow flies, north of Auckland. The previous day he had dived to 24 m for 25 minutes. He dived to 27 m, swimming hard in a current, for crayfish, for 17 minutes. On the surface at the end of the dive, he was conscious and inflated his buoyancy compensator. He developed pins and needles and numbness, then lost consciousness for 2 minutes. He did not vomit or cough up blood.

In the previous 2 years he had noted paraesthesias and elbow pain on at least 3 occasions after diving, and had done at least one bounce dive to 69 m. He had had a normal chest X-ray 5 days before the accident. As a result his GP advised that he was safe to dive, although he had had a cough and recurrent chest infections for 6 months before his accident.

He was rapidly taken by boat to Te Ngaere Bay, a distance of some 10 km. Assistance was sought by CB radio en route, advising the then Winfield helicopter service at 1000. An ambulance met the boat and oxygen by mask was started 30 minutes after surfacing. He was conscious in an ambulance to Kaeo Hospital, a journey of about 15-20 km. His breathing had become laboured 1 hour post dive. The helicopter arrived at 1330, 3 and a half hours after being notified. By this time he was unconscious again and needed stabilisation to travel. The helicopter was low on fuel so they flew about 50 km north west to Kaitaia to refuel. They flew to Auckland down the West Coast, stopping about every 15 minutes to allow the paramedic to reassess his condition. The helicopter covered about 250 km to reach the Royal New Zealand Navy Hospital at 1600, six and a quarter hours after he surfaced.

He was recompressed, then had to be decompressed early because of increasing respiratory difficulty and transferred to the Critical Care Unit at Auckland Public Hospital. He survived as a T6 paraplegic. His marriage failed after his accident. Sadly his accident was before the ICU-under-pressure facilities were installed at the Slark Hyperbaric Unit.

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EVACUATION METHODS IN DIVING INJURIES

Mike Bennett

Key Words

Accident, transport.

Introduction

The evacuation and retrieval of diving injuries is an unavoidable issue for those involved in the treatment of decompression illness (DCI) in the recreational diver and is likely to remain so for the foreseeable future. This is because civilian hyperbaric facilities in Australasia are relatively widely scattered and the best dive sites are often remote from a treatment chamber. This means that acutely unwell divers will require transfer over considerable distances in order to reach definitive care. This paper outlines the principles involved in selecting the appropriate transport and illustrates some of these with reference to recent cases at the Prince of Wales Hospital.

Retrieval options

There are four methods by which a patient with DCI may reach a hyperbaric facility. These are by private car or public transport (usually without seeing a doctor first) or by ambulance (road, helicopter or fixed wing). While the proportions alter according to local resources and geography, for many facilities all will be utilised to some extent. In New South Wales (NSW) approximately half our patients arrive by car or public transport without prior medical attention, while for the remainder ground, rotary wing and fixed wing ambulances are roughly equally utilised.[1] At times the particular form of ambulance used may be dictated by circumstance or economic necessity, but often a decision will have to be made. Such decisions should be informed by a knowledge of the available resources (including vehicles, crew and clinical equipement), optimal communications and experience of the practical capabilities of each crew/ambulance combination available. A local appraisal of topography, weather and access by a person at the scene is often invaluable.

The traditional approach to optimal transfer has relied on a number of principles which can often be in conflict. Chiefly, these principles are:

1 That the time interval from exiting the water (sometimes time from onset of symptoms is preferred) to compression is prognostically important.
2 That the altitude attained during retrieval may affect disease progression and ultimately prognosis.
3 The initial severity of the injury is also prognostically important.

It is not yet clearly demonstrated which, if any, of these principles is more important in determining outcome and should therefore take precedence in the case of conflict. Some attempt has been made to relate delay to treatment and outcome, but without any firm conclusions being drawn.[1] The 1996 edition of the Divers Alert Network (DAN) report strongly suggests such a relationship, but relates delay to treatment with residual symptoms after the first treatment only, rather than on completion of treatment course.[2] Theoretical considerations and many anecdotal reports suggest that altitude stress is important and there has been at least one local case of litigation on this basis. A number of severity scoring systems have been proposed and appear to have some prognostic value.[3,4]

Table 1 lists a number of factors which may be important in the transport of patients following diving accidents and the performance of three transport platforms with regard to each. These are discussed below.

Response time is rapid with dedicated retrieval vehicles, both rotary wing and road ambulances, as there is little preparation to be made before call out. This reflects the primary purpose of such vehicles to respond to emergency situations. The response time for a helicopter will be dramatically altered if retrieval is only a secondary function. Fixed wing craft inevitably have a longer response time, particularly if operating out of a busy airport. The figures in Table 1 are those achieved by the New South Wales retrieval system.

Once a retrieval is underway speed has a powerful influence on the interval from dive to compression. Analysis of our experience in NSW suggests that the combination of response time and speed results in a "doughnut" concept of those retrievals for which a helicopter is appropriate. Within the Sydney metropolitan

TABLE 1

SOME FACTORS FOR CONSIDERATION WHEN CHOOSING THE MOST APPROPRIATE TRANSPORT PLATFORM

	Road	Fixed Wing	Helicopter
Response time	Minutes	1 hour	10 minutes
Speed	60 km/hr	550 km/hr	200 km/hr
Altitude	Topography dictates	Sea level equivalent	Day 50 m Night 800 m
Access	Road system	Airfield	Versatile
Weather	Independent	VFR/IFR*	VFR (IFR)*
Availability	Excellent	Variable	Variable
Crew	Graded response	Variable	Variable. Often have specific training
Vibration	0-5 Hz, low magnitude	Bi-phasic,1-12 Hz and 100-600 Hz, high magnitude	6-34 Hz, moderate magnitude

*VFR: visual flight regulations, IFR: instrument flight regulations.

area, ground ambulances are almost instantly despatched and helicopters rarely deliver the patient significantly more rapidly. Further than 350 to 400 km, fixed wing transfer is usually the preferred option as the aircraft's greater speed through the air overcomes the longer response time. This leaves an area of operations from about 40 km to 400 km in which helicopters are the superior option if time to definitive treatment is considered in isolation.

Altitude stress is a problem particularly identified with unpressurised aircraft or commercial aircraft with partial pressurisation (a typical long-haul flight cruises at a cabin pressure equivalent to 1,500-2,500 m). Many dedicated fixed wing ambulances are capable of being fully pressurised (to sea level) which eliminates the problems of crossing mountains. Road transport is highly dependent on topography and any planned retrieval where altitude is critical should be examined closely. It is often a helicopter flying at low altitude over the ocean which results in least altitude exposure. However, at night the minimum safe operating altitudes for helicopters are considerably higher than in daylight, commonly around 600 m.

Access to an injured diver may sometimes be a problem. While the road system in many parts of the world is extensive, there are usually some remote spots where a walk or boat ride is the only way in. Under these circumstances, a helicopter or ground party will clearly be required to bring help to the scene. Indeed, helicopters with a personnel winch and rappel-capable emergency medical staff are irreplaceable under these circumstances.

Weather can disrupt the best laid plans for a retrieval and any effort to retrieve a diver by air should only be undertaken after consulting the appropriate meteorological authorities. Poor weather or freezing conditions may ground, or force higher, many aircraft. This is particularly true of helicopters.

The training and abilities of retrieval medical personnel may influence the choice of transport platform beyond the physical capabilities of the platform itself. Highly trained and experienced medical and paramedical crew are a valuable resource and may need to be relocated with their sophisticated equipment by a means which would otherwise be rejected. In NSW, we are fortunate to have a retrieval network which includes several specialist-based medical teams which may be despatched rapidly by any transport platform. Part of the complex task of retrieval co-ordination is to match the skills required for a particular retrieval with the resources available.

It has been suggested that the vibration characteristics of different platforms may adversely effect the patient with DCI. In particular, high frequency, energetic vibration may adversely effect bubble generation, evolution or distribution. There is, as yet, no clinical data to support or reject this hypothesis. Bosshard and Yeo[5] studied the vibration characteristics of the three types of ambulance in a study concerned with the transport of spinal injured patients. They concluded that the helicopter studied (a twin engined Squirrel) produced vibration of moderate magnitude in a predictable range of frequencies. Vibration in the fixed wing aircraft (Beechcraft King Air) was more energetic and of higher frequency during flight and of very low frequency but equal magnitude on take-off and landing. The road vehicle was least challenging in terms of vibration energy. The significance of these findings in relation to bubble behaviour is unknown.

Recent experience in NSW

The last 133 cases treated at the Prince of Wales Hospital Hyperbaric Unit have been analysed retrospectively with regard to transport platform, time to recompression, altitude stress and resolution of symptoms at discharge. The results are summarised in Table 2. A more detailed analysis of a similar group has been published previously.[1] The numbers are too small for definite conclusions about the relative importance of the factors discussed and we are collecting prospective data for a more formal analysis.

Table 2 suggests that those who self-refer take significantly longer to seek compression than those who arrive by fixed wing or road ambulances. The helicopter group have been omitted because the high incidence of cerebral arterial gas embolism (CAGE)-type disease and markedly shorter intervals to compression. The difference, on average, of 28 hours is statistically significant ($P<0.001$, 95% CI 14.4 hours to 41.6 hours), however the longer interval from symptoms to compression does not lead to a significantly increased rate of incomplete resolution (38% in the self-referred group versus 28% in the fixed wing/road group, χ^2 0.42, $P=0.52$).

There is no evidence of a benefit in terms of recovery grade at discharge between retrieval at low cabin altitude in the fixed wing aircraft and transfer by road ambulance (average cabin altitude 52 m by fixed wing and 200 m by road, χ^2 0.64, $P=0.44$). Better prospective data on a larger group may enable us to tease out the relative importance of time delays, altitude exposure and severity.

Case 1

A 22 year old diver of moderate experience had been diving, for one week, with a group on an island three and a half hours flight off the coast of NSW. She had not made more than two dives in a single day for a total of 12 dives over the week and each individual dive was unremarkable. She had not breached the sports tables she was using.

Approximately four hours after the last of these dives she became unwell, complaining of lethargy, malaise and

TABLE 2

TRANSPORT MODE, ALTITUDE AND RESOLUTION FOR 133 DIVERS WITH DCI

Retrieval Method	Patient numbers	Mean maximum altitude	Average interval to compression	Full resolution		Incomplete resolution	
Self-referral	69	200 m	52.0 h	50	(72.5%)	19	(27.5%)
Fixed wing	23	52 m	27.7 h	19	(82.6%)	4	(17.4%)
Rotary wing	23	150 m	5.0 h	17	(73.9%)	6	(26.1%)
Road	18	200 m	21.0 h	13	(72.2%)	5	(27.8%)

paraesthesia in both hands. There were no objective signs. She sought help at the local hospital and one and a half hours after the onset of symptoms was on high flow oxygen through a non-rebreathing mask with reservoir. The attending medical officer contacted our unit and by this time her symptoms had resolved about 75%.

The regular commercial return flight from the island was due to leave in 2 hours and it was quickly determined that space was available for her and an attendant should we wish to use this flight for repatriation. Alternatively, the NSW Air Ambulance (4 Beechcraft King Air pressurised aeroplanes) was fully employed elsewhere and would not be able to reach the patient with nurse/paramedic team for approximately six hours. To this would need to be added turnaround time on the island, return flight and the short ground trip in Sydney. Total retrieval times would therefore be about 6 hours for the commercial option and 12 hours for the dedicated retrieval vehicle.

THE RETRIEVAL DILEMMA

Which of the two principles, minimising the interval to definitive treatment or minimising altitude stress, was the more important? The commercial flight was discussed but the dispatching medical team on the island were uncomfortable with this and elected to wait for the Air Ambulance.

OUTCOME

Total delay from symptom onset to compression was 16 hours. She required an initial RN Table 62 and two further oxygen soaks (2.4 bar for 90 minutes each), before being discharged well. She had some minor recurrence of paraesthesia which settled over the next couple of weeks and was completely recovered at review six weeks after discharge.

Case 2

A 32 year old experienced male diver had been diving on the south coast of NSW over the weekend. He had done 5 separate dives over Saturday and Sunday, during the last of which he had attained a maximum depth of 46 m and a profile which exceeded the DCIEM Tables. This dive was the second for the day but the deeper of the two and he had completed the dive in the late afternoon.

About 30 minutes after surfacing he began to complain of pain in the right shoulder, right elbow and both ankles. There was some associated paraesthesia in the right hand, he felt unsteady on his feet and gradually developed an occipital headache which worsened over the next 30 minutes while en route to the local hospital.

On arrival he walked into the Emergency Department and after giving a brief history and accurate diagnosis to the nursing staff, our unit was contacted. Concurrent medical examination was unremarkable except for a very poor Romberg's (a few seconds only), which was performed before lying him flat and administering high-flow oxygen and intravenous fluids. There was little or no improvement in his symptoms after this first aid was instituted.

The hospital is located 160 km (about 2.5 hours by road) from Sydney and has both a helicopter pad in the grounds and a military airfield nearby open to emergency vehicles if required. The road trip requires a maximum altitude of about 500 m with many short ascents and descents.

THE RETRIEVAL DILEMMA

Retrieval options all presented some problems. Road transfer is discouraged because it involves altitude stress and the loss of an ambulance and crew from the region for an extended period. No medical attendant would be possible. Total time from hospital arrival to compression would be about three hours.

Helicopter transfer with doctor/paramedic crew is the preferred option during the day as low-level (<100 m) flight is possible and specialist personnel will reach the patient in minimal time, little more than the 30 minute helicopter flight. At night however, the minimum safe altitude is over 600 m and may be higher in bad weather. Total time from hospital arrival to compression would be about two hours.

Fixed wing ambulance transfer is not usually contemplated for such a short flight but given the constraints above was considered. Such a vehicle enables sea level cabin pressure on the return leg and a paramedic/nurse crew which may be supplemented by a retrieval medical officer if required. There is a 15 minute road ambulance trip from the hospital to the local airfield. Total time from hospital arrival to compression would be about 3.5 hours.

OUTCOME

Because of the expected return in the hours of darkness, the unwillingness to consign the patient to a lengthy road trip without specialist attendants and little evidence that his symptoms were settling with first aid measures, it was decided to transfer the patient by fixed wing aircraft. This expensive option was, in fact, subject to unavoidable operational delay and the actual interval from symptom onset to compression was 7.5 hours. He was treated initially with an RN Table 62 with rapid resolution of symptoms and required one further short table before being discharged well. He reported no return of symptoms and continued well and resumed his diving six weeks after the incident.

Conclusions

The retrieval of diving injuries can be complicated by a number of factors which impinge on the decision as to which transport method is most appropriate and the level of medical attendance required. Rational choice depends on the retrieval decisions being taken by those with experience both in the primary pathology and the practicalities of the retrieval system.

It is not yet possible for decisions to be made on the basis of good evidence as to which strategies provide optimal outcomes. Further investigation as to the important, modifiable determinants of such outcomes (if any) is needed.

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NORTHLAND RESCUE HELICOPTER HI-LINE TRANSFERS

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Key Words

Accidents, equipment, rescue.

During the 1997 SPUMS Annual Scientific meeting the Northland Emergency Services Trust (NEST) helicopter lowered, and recovered, a crewman onto one of the diving vessels, during the mid-day surface interval, as a demonstration of how helicopter rescue of divers is performed. This paper includes information taken from the NEST poster display and pamphlet available at the meeting.

Being under a hovering helicopter is very windy and noisy and conversation is difficult without a loud-hailer. Being rescued from a boat is much more comfortable than being rescued from the sea or a life raft. In my experience a small life raft is blown along by the helicopter down draft making it difficult for the rafter to reach the strop. After five attempts to bring the stop within reach had failed I went into the water, the Solent in February, and swam to the strop. Being lifted out of the water was wonderful, but being winched up, dangling unable to help oneself, was still a scary experience. How much easier would it have been using if the Royal Navy had been using modern techniques, lowering a crewman to assist the casualty, back in 1954.

Using the Hi-Line technique described below the arrival of the helicopter crewman was a swift and simple operation. The weighted line was dropped (Figure 1), when the helicopter was well clear of the ship's various overhead obstructions, onto the dive boat bow, where the boat crew hauled in the line until it was tight. Then the helicopter moved to one side of the boat and the winchman prepared to descend. As the winch cable was paid out the boat crew maintained tension on the Hi-line so pulling the crewman towards the boat, over the guard rail and onto the deck. Here he disconnected himself from the cable. After a short