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DIVER RESCUE, DECOMPRESSION SICKNESS AND ITS IN WATER TREATMENT USING OXYGEN

John Knight

To rescue a diver you first have to find him. It is difficult to see divers in the water from a small boat. It is difficult for divers to see each other in the water, because of water movement and waves coming between them. The New Zealanders have had problems in the past with lost divers (see page 163) and they have produced a very effective aid in the form of an inflatable plastic tube called the Safety Sausage.[1](Figure 1) The Safety Sausage rolls up into a little bundle that fits easily in the pocket of a buoyancy compensator. When needed it is unrolled. The open end is put over the diver's regulator. One hand holds it tight round the regulator hose while the other presses the purge button. Suddenly there is a 2.4 m (8 foot) sausage of plastic, 10 cm (4 inches) in diameter, standing up out of the water clearly marking the diver's position. It is very much easier to see something sticking up out of the water than to see something on the water surface. It is quite easy to spot a mast against the horizon when one is looking for a boat. It is just as easy to spot a Safety Sausage against the horizon when looking for a diver. The Safety Sausage is wider than most small boats' masts, although not so high.

It is important that the Safety Sausage be held tightly round the regulator hose otherwise most of the air finds it easier to escape underwater rather than go up the tubing. It is a device that will sell for around $10.00 in Australian dive shops, so is a lot cheaper than a flare and unlike a flare can be used many times.

Having rescued the diver in an emergency, one has to treat any problems. One problem that is better avoided than treated is decompression sickness.

How to avoid decompression sickness (DCS)

It is usually recommended that one should always do no-stop dives. The next recommendation is always stay well within the decompression tables. What this means varies from speaker to speaker. It is important, in fact essential, when using tables that one knows the maximum depth reached. This means using a recently calibrated depth gauge. Depth gauges have been shown on many surveys to be inaccurate. There are two forms of inaccuracy. The safe one is where the gauge reads deep, because the diver thinks he or she is deeper than he is. The unsafe one is when the gauge reads shallow. This is a very unsafe form of inaccuracy as the diver thinks he is shallower than he or she actually is and dives deeper than the planned dive. There are some gauges that are inaccurate over part of their range only, so it is essential that one knows the inaccuracies of one's gauge, which means regular testing.

The next necessity with tables is to know the bottom time which requires a waterproof watch, or one of the many devices that automatically turn themselves on when a certain pressure is reached, and turn themselves off when they return to that pressure. These give a total dive time rather than a bottom time, defined as the period from the leaving the surface to starting the ascent, which is needed to work out most tables.

One should never ascend faster than 18 metres (60 feet) a minute and preferably much slower. It is quite clear that many cases of decompression sickness in Australia, and I suspect in other parts of the world, are associated with rapid ascents. I believe the correct ascent rate should be no faster than 10 metres a minute and preferably slower. One should always do a stop at 5 metres, or thereabouts, on every dive, so that there is time to let the lungs filter out any bubbles that have formed on the way from the bottom to 5 metres.

If one must do a decompression dive, one should decompress for the next deeper depth and the next longer time. A shot rope should be used because there is no other way that one can maintain depth accurately. Remember that currents and tides will swing the diver away from the vertical, so that the marked position on the shot rope will no longer be at that depth. One should always have extra air on the shot rope in case the decompressing diver runs out of air. After diving one should not fly or cross mountains for at least 12 hours and it is a lot better and safer to make it 24 hours.

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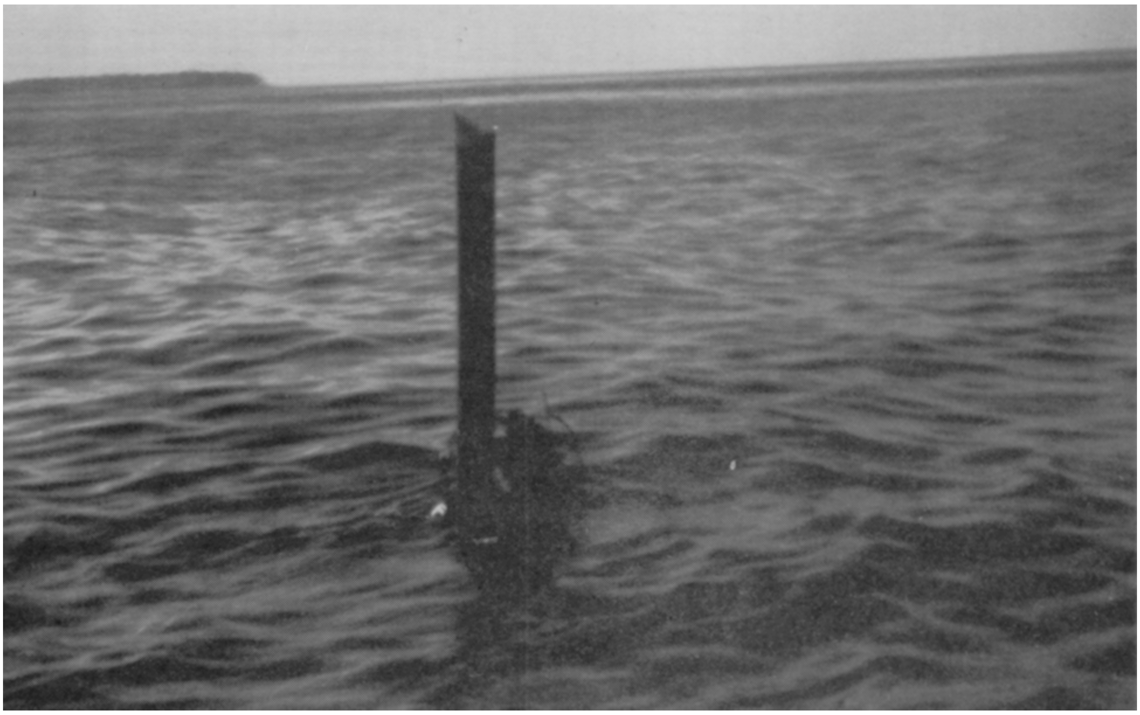

Figure 1 Diver and Safety Sausage at sea.

READ THIS BEFORE USING THE TABLES

1. Bottom time starts on leaving the surface and stops on starting the ascent.
2. Use the deepest depth of the dive as the depth of the dive for calculation.
3. If the deepest depth of the dive is between two depths in the table use the greater depth for calculations.
4. If the time is between two times in the table use the longer time for calculations.
5. After a dive calculate the repetitive group.
6. After the surface interval calculate the new repetitive group.
7. Using the planned depth of the next dive enter the repetitive dive table to find the no-decompression bottom time available for that repetitive group and depth.

ASCENT RATE 10m A MINUTE.

ON ALL DIVES DEEPER THAN 9m (30ft) DO A 3-5 MINUTE SAFETY STOP AT 3-5 M.

USE THE TOTAL TIME UNDERWATER (BOTTOM TIME + ASCENT TIME + SAFETY STOP TIME) TO FIND THE REPETITIVE GROUP AT THE END OF THE DIVE.

TABLE 4

MODIFIED AIR DECOMPRESSION TABLE*

Depth m	Depth feet	Bottom Time minutes	Decompression Stops minutes at 10 feet	Repetitive group
18	60	70	7	K
		80	12	L
21	70	60	13	K
		70	19	L
24	80	50	15	K
		60	22	L
27	90	40	12	J
		50	23	L
30	100	30	8	I
		40	20	K
33	110	25	8	H
		30	12	J
36	120	20	7	H
		25	11	I
39	130	15	6	F
		20	10	H
42	140	15	7	G
		20	11	I
45	150	5	5	C
		10	6	E

* FOR THOSE WHO ACCIDENTALLY EXCEED THE NO-DECOMPRESSION LIMITS

TO CALCULATE THE REPETITIVE GROUP AFTER A REPETITIVE DIVE.

3rd DIVES BELOW 9m(30 feet) ARE NOT RECOMMENDED.
A REPETITIVE DIVE IS ANY DIVE WITHIN 12 HOURS OF THE LAST DIVE.

1. Subtract the actual bottom time of the repetitive dive from the bottom time available in table 3 to get an answer in minutes.
2. Subtract this time difference from the Bassett Bottom Time limits in table 1. The answer is the equivalent bottom time of the repetitive dive.
3. Add the ascent time and the safety stop time to the answer in 2. This is the equivalent total time underwater of the repetitive dive.
4. Use this time to enter table 1 to find the repetitive group at the end of the dive.

A 2B PENCIL WRITES WELL ON THIS PLASTIC AND IS EASILY RUBBED OUT.

	EXAMPLE	**2nd dive**	**3rd dive***
Repetitive Group before the dive.	B		
Proposed depth of dive	24 m		
Bottom time available	22 min	min	min
- Actual bottom time	20 min	min	min
= Difference	2 min	min	min
Bassett Bottom Time limit	30 min	min	min
- Difference	2 min	min	min
= Equivalent Bottom Time	28 min	min	min
+ Ascent time	3 min	min	min
+ Safety stop time	5 min	+ 5 min	+ 5 min
= Equivalent total time underwater	36 min	min	min
Repetitive group at the end of the dive	I		

The RESIDUAL NITROGEN TIME can be found by subtracting the MAXIMUM TIME AVAILABLE FOR A REPETITIVE DIVE (Table 3) from the BASSETT BOTTOM TIME LIMITS (column 3 of table 1).

Figure 3. Bassett Tables (Back)

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Staying "within the tables", to make them safer, requires thought and memory, both of which are affected under water. It is easier to use as safe a set of decompression tables as one can find. At the moment it is my opinion that the safest tables that are readily available in Australia are the Bassett Tables that John Lippman and I have published.(Figures 2 and 3)[2] They have a number of safety factors built in. No-decompression times are shorter because a lesser supersaturation ratio has been used in the mathematics. There is a safety stop at 3 to 5 metres for 3 to 5 minutes on all dives below 9 metres. We have amended the ascent rate from 18 m (60 ft) a minute to 10 metres a minute. So there are three safety factors for the first dive. For the second dive one uses the total time under water for calculating the repetitive group. Then using the United States Navy (USN) surface interval table, to find the USN Residual Nitrogen time. Taking this time away from the Bassett Limits gives the table for the second dive which only shows the time available for that second dive. This builds in two more safety factors.

To use the tables one selects from column 1 or 2 in Table 1 the depth one intends to dive to, and from column 3 the no-stop time available for the first dive. At the end of the dive one runs a finger across the table to find a number equal to or greater than the total time spent in the water. Running the finger down that column will find the repetitive group letter at the end of the dive. Run the finger vertically down to find the same letter in Table 2, now the finger travels across to the left to find the surface interval. When the surface interval is found run the finger down to the letters at the bottom of that table to find the new repetitive group. Continue down into Table 3 which shows the time available for each depth in that repetitive group so that the second dive does not exceed the Bassett no-decompression Limits.

The table has the advantage of being very easy to read under water, because of the yellow highlighting of alternate lines and columns, so that if one does drift deeper than one intended one can recalculate the dive profile immediately. Besides being safer than the United States Navy Tables, the table is extremely easy to use as it only requires the diver to be able to read and move his finger horizontally and vertically. It is an unfortunate fact that many divers are unable to work out for themselves the time available for their second dive. Some have great difficulty even working out the time available for the first dive. If one drifts lower than one intended and finds one has exceeded the no-stop limits in Table 1 of the Bassett Tables turn the card over

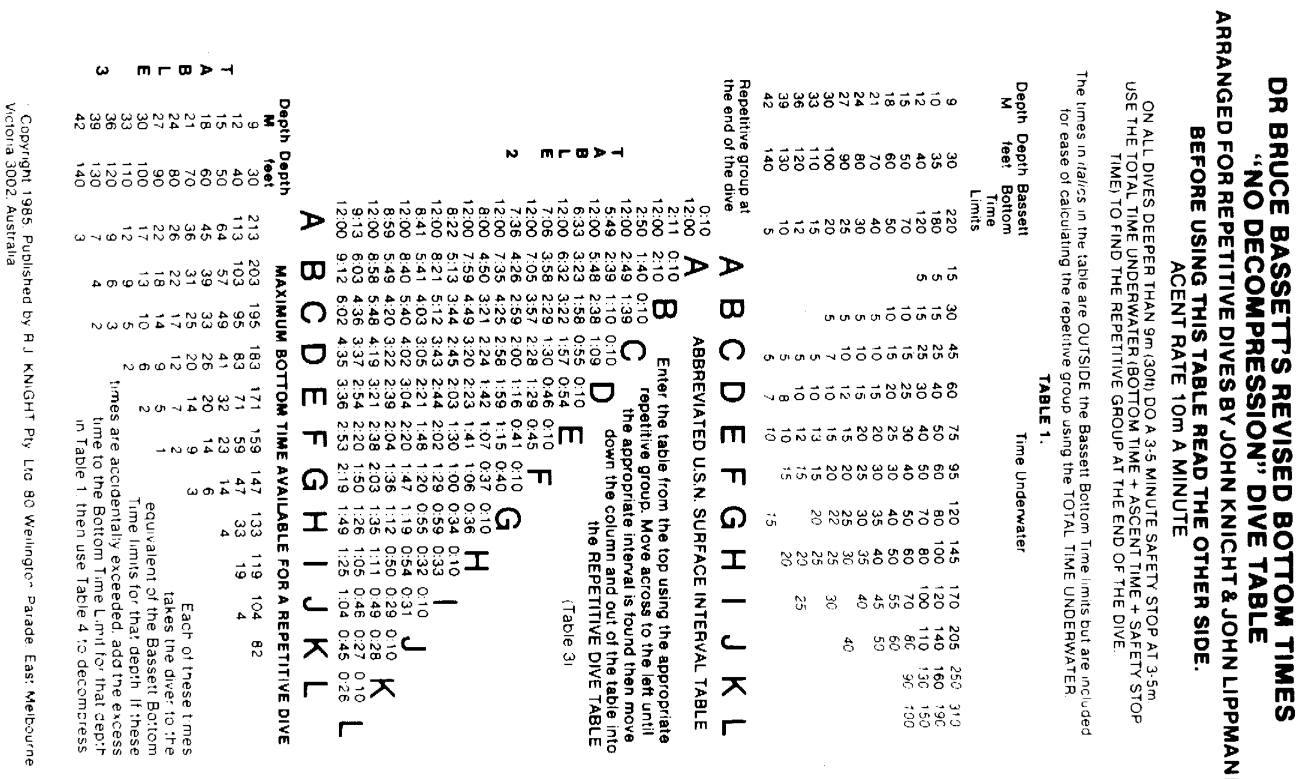

Figure 2. Bassett Tables (Front). The tables are printed in waterproof ink on plastic and are varnished for extra protection. They fold easily to fit a buoyancy compensator pocket. Yellow highlighting makes rows and columns easy to follow.

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and there is a short decompression table for those who have drifted lower than they intended (Figure 3). There is also the way to use the tables and a method of calculating one's repetitive group at the end of the second dive. So that if one wishes to do a third dive, which I do not recommend, it is possible to work out the equivalent bottom time of the second dive. This allows one to enter Table 1 (Figure 2) and, using the equivalent total time underwater, find the repetitive group at the end of the second dive then one can use the surface interval table and Table 3 to get the time available for a third dive.

How to recognise DCS

Most people who develop decompression sickness get their symptoms fairly soon after emerging from the water. The figures vary, but it is a fairly standard statement that 80 per cent come on within one hour and 50 per cent within 30 minutes.

The symptoms of decompression sickness are extremely wide ranging and include malaise, weakness, exhaustion, skin itching and skin rash, nausea, vomiting and abdominal pain, numbness, tingling and giddiness, joint and limb pains, disturbances of nerve function and difficulty with breathing (the chokes). Disturbances of nerve function can cover anything from patches of anaesthesia or analgesia to frank paralysis.

Two things that most of the text books do not yet include is that the personality of the diver is often affected by decompression sickness and that many divers have great difficulty in accepting that they might have decompression sickness. It is essential that a diver's buddy, who notices that the diver's personality has changed after a dive, takes steps to get the diver to a recompression chamber as soon as possible.

It is becoming more and more obvious that limb bends and skin bends are often accompanied by central nervous system changes. That means that there are bubbles in the central nervous system. CNS changes due to DCS are often vague and subjective, but reverse dramatically with recompression. Divers have to be encouraged to believe that any problem occurring after a dive are due to that dive until proven otherwise.

It is usually said that the presenting symptoms of decompression sickness are mostly pain only. Rivera published a series of 935 cases from the US Navy in 1963.[3] Presentation was with pain only in 82.7%; other 10.3%; cerebral, including inner ear, 6.4%; spinal 0.2%; and cardiorespiratory 0.4%. That was USN diving with very carefully controlled divers (Table 1). Twelve years later, Erde and Edmonds,[4] who treated sports divers presenting for treatment in Hawaii and Sydney, had very different figures. Pain only was 33%; other was 15%; cerebral, including inner ear, was 33%; spinal was 13%; both spinal and cerebral 5%; and cardiorespiratory 1%. These divers were doing deep dives and many of them made very rapid ascents (Table 2). So it does seem that the way the diver dives will influence the way he is affected.

Table 1

PRESENTING SYMPTOMS OF DECOMPRESSION SICKNESS, US NAVY

From Rivera (1963) 935 cases

Cerebral (including inner ear)	6.4%
Spinal	0.2%
Cardiorespiratory	0.4%
Pain only	82.7%
Other	10.3%

Table 2

PRESENTING SYMPTOMS OF DECOMPRESSION SICKNESS, SPORTS DIVERS

From Erde and Edmonds 1975. 100 cases

Cerebral (including inner ear)	33.0%
Cerebral with Spinal	5.0%
Spinal only	13.0%
Cardiorespiratory	1.0%
Pain only	33.0%

Emergency treatment

Divers do not come to the surface wearing a little label saying "I have decompression sickness". They come to the surface feeling terrible or are unconscious, or develop symptoms after they get out of the water. A flow chart (Figure 4)[5] starts, "Do not panic". This is because accidents are rare occurrences to the average diver, and the average diver is not going to practice his diving first aid very often and when one is faced with frightening and unfamiliar circumstances it is very easy to run round in circles, metaphorically, doing very little.

The first question one has to ask oneself when dealing with a diver who has been involved in an accident in the water, is "Is he injured and bleeding to death". If he is bleeding briskly, squirting blood, the first thing to do is to stop that bleeding. Because no matter what other resuscitation you do, that man or woman can die from blood loss if a major artery is bleeding. Once massive bleeding is under control the next question the first aider has to ask is, "Is the patient conscious or unconscious?" and this is rapidly answered by speaking to the victim. If there is no reply one has to

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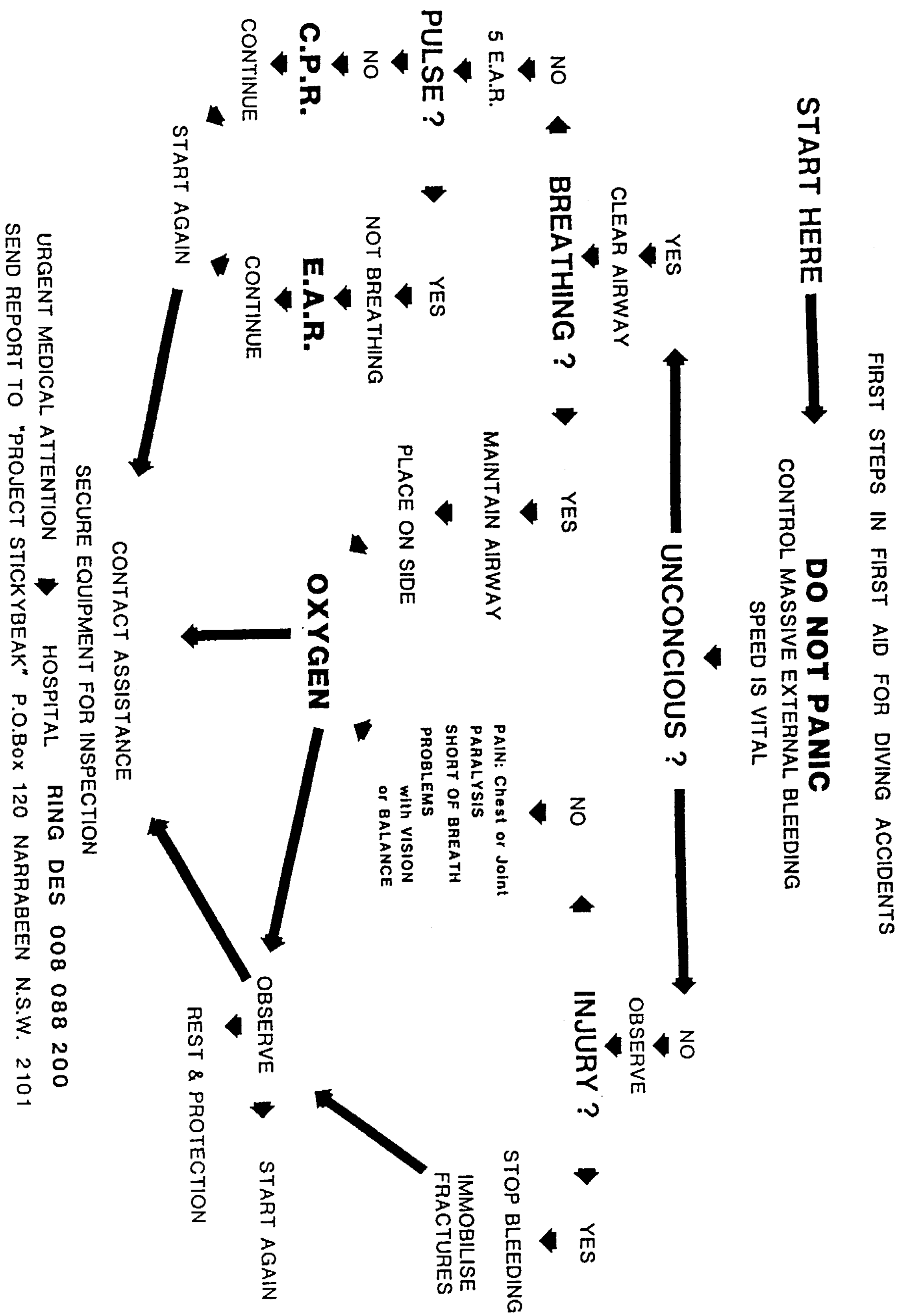

Figure 4 Diver rescue flow chart

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assume that he or she is unconscious. The next question is, "Is he or she breathing?". If he or she is, the next thing to do is to roll him or her on their side in the coma position and observe how he or she does. If he or she is not breathing, it is necessary to give expired air resuscitation (EAR) and the current recommendation in Australia is to start with 5 quick breaths, then feel for a pulse. If there is a pulse, carry on with EAR. If there is no pulse there one has to start CPR. Either is quite a performance to carry out in a crowded diving boat. While giving EAR it is possible to give oxygen enrichment. The rescuer takes a breath from his own regulator attached to a Bendeez adaptor 6 screwed into an oxygen cylinder, between each puff into the patient. In this way a high oxygen concentration can be given for the patient.

A conscious patient has to be assessed for injury and if there is none one has to observe to see whether he or she develops symptoms that might be due to decompression sickness or air embolism, such as pain, giddiness, difficulty with breathing, paresis or paralysis and unconsciousness. If the patient has an injury it has to be dealt with and the patient observed.

All unconscious patients should be given oxygen as soon as possible. All patients having EAR or CPR should have oxygen. Once the patient is breathing on his or her own he or she should have 100% oxygen. With a diver it is fairly easy to give 100% oxygen by putting a regulator on a Bendeez and putting the regulator in the diver's mouth. There are problems with this if the diver's mouth will not open, but usually it will.

If somebody develops decompression sickness symptoms, they must go on oxygen to try and slow down progression of the symptoms while they are on the way to a recompression facility. The aim of giving oxygen for a decompression diving accident is to exclude nitrogen from that person's lungs. If one can exclude further nitrogen from that person's lungs it vastly increases the outward gradient of any nitrogen the diver has absorbed. Oxygen is most easily given in Australia by having a 'D' or larger size cylinder of oxygen with the diving party and a Bendeez adaptor which allows the diver's own regulator, which he is certain to have with him, to be attached to the Bendeez and so the diver gets oxygen through his own regulator. This method works with divers because divers have been taught to breath through their mouths. It does not work with people who are not divers, as they do not like breathing through their mouths. For them one must use a bag and mask set up, which is a little bit more complicated because one needs an oxygen regulator, a flow meter, 2 m of tubing, a mask, a bag and an expiratory valve, and the whole lot costs quite a lot of money. Table 3 shows the CIG Medishield Part Numbers and December 1987 prices. The bag and mask has the snag that unless it is put on by an anaesthetist, an intensive care nurse, or mobile intensive care ambulance officer, the mask is unlikely to achieve a complete seal, and if the patient is bearded it is almost inevitable that it will not get a complete seal except at the price of extreme pressure on the person's face. If there is any leak between the mask and the patient's face he or she will not receive 100% oxygen. In the effort to avoid giving the patient more nitrogen, I prefer to use the Bendeez.

Table 3

CIG-MEDISHIELD EQUIPMENT NEEDED FOR GIVING 100 % OXYGEN BY MASK

Description	Part number	Price $A
Oxygen Regulator (to fit a large oxygen cylinder)		
	518800	139.40
Flowmeter	TM 105	82.40
Tubing (2m)	YR 62 per metre	.60
Expiratory valve	DF 655	163.20
4 litre bag	OBM 372764	11.90
Male connector (to connect bag to mask)		
	OBM 1353552	32.05
Resuscitation face mask (adult)		
	515743	23.60
Clausen head harness	OBM 301061	17.15

All divers should have a copy of the Diving Emergency Handbook, by John Lippman and Stan Bugg. A new revised edition[7] has just recently been produced. On its back page is a flow chart similar to the one in Figure 4, which includes the Diver Emergency Service (DES) number.

The Diver Emergency Service, is contacted by dialling 008 088 200. A telephone rings in the Intensive Care Unit of the Royal Adelaide Hospital. It is answered immediately and the diver is put onto the duty Hyperbaric Consultant who may be in any part of Australia. It is a highly sophisticated system of switching telephone calls around the country. The Australian Underwater Federation (AUF) publishes a plastic card which is headed "Diving Emergency Service", giving the phone number. This plastic card is available in dive shops or from the AUF. On one side it has the telephone number, on the other it has the list of what to do. The routine is to telephone the DES number (008 088 200), state that it is a diving emergency, provide details of the incident, depth, time, location and symptoms, wait for advice and directions, act on the advice and directions, and follow up by informing "Project Stickybeak" by writing to PO Box 120, NARRABEEN NSW 2101. All information is treated as confidential and all identifying details are removed before any information is made public. Dr Douglas Walker is interested in gathering details of all diving accidents and accidents that have been avoided not only in fatal or nearly fatal ones.

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From overseas, one can contact DES by dialling ISD 61 8 223 28 555.

The treatment of DCS

The treatment of DCS is recompression, oxygen and fluids, preferably very soon after the onset of symptom, as this gives the best chance of recovery. This treatment is best given in a recompression chamber (RCC) equipped with intensive care facilities, which means a hospital hyperbaric unit. However, this is not always possible and there may be long delays reaching a RCC from remote areas.

Underwater oxygen therapy

Oxygen in the water treatment, hyperbaric treatment, was designed for remote locations, places where there was a long delay before the patient could hope to get to a recompression chamber. The typical scenario, when this equipment was designed by Carl Edmonds[8] in the late 1960s and early 1970s, was that people would develop DCS in the relatively less remote parts of the Pacific and even if they immediately got through to the RAN School of Underwater Medicine, it would be over 24 hours before they could possibly be retrieved. There were delays involved getting a Hercules airborne and flown to wherever the patient was, and it had to arrive in daylight because usually the island did not have landing lights on its airstrip. Then it often had to then wait overnight and take off the next morning. Sometimes it took two days or more to get a patient to Sydney. Remember that the sooner a person is recompressed, the better chance he or she has of a useful clinical result.

What are the advantages of hyperbaric oxygen in water? There are none if one is close to a recompression chamber. The diver must be a long time from a recompression chamber before in water oxygen has an advantage. By long time, I mean that it will take more than 6 hours to reach the chamber. I think that if I had a paraplegia I would bring that time down to one hour. It is a warm water, tropical island, treatment. It is a treatment for out of the way places, with long delays in reaching a recompression chamber. Although Carl Edmonds has tried it in the Antarctic, I consider that in southern Australian waters, without extra heating, one would convert a decompression sickness patient into a patient suffering from a combination of decompression sickness and hypothermia. Its major advantage is that no nitrogen is added to the body during treatment. The bubbles are approximately halved in volume, whatever shape of size they are. With round bubbles the diameter is reduced by approximately 20%. The diameter of a long bubble in a blood vessel will not be reduced at all, but the length will be reduced, so reducing the frictional resistance and increasing the chances of the bubble moving on. There is a large nitrogen pressure gradient out of the bubble. There is increased oxygenation of the tissues that are being perfused. Also there is increased oxygenation of the tissues that are not being perfused because oxygen will diffuse much further because of the high pressure gradient.

There is said to be no risk of oxygen toxicity. The only case reported of oxygen toxicity using this system[9] was some years ago and it is disputed by some people.[10] There is no risk of decompression sickness for the attendants. Finally, wet suits are still effective insulation at 9m.

What does one need to give the treatment in a remote part of the world with warm water? Emergency decompression in water using oxygen requires a full face mask. The chances of a person having an oxygen convulsion under water are low resting at 9m but it is always possible. A person who has not got a full face mask on when he has a fit is almost certainly going to drown. So a full face mask should be used. If the patient vomits under water, he or she vomits into the mask. It is a relatively simple matter to clear the vomit from the mask. A finger is put under the chin and the mask lifted up a little bit and the vomit will trickle out into the water. The patient needs a wet suit including a hood. He or she needs a shot rope to hang onto. A rope is needed to support the patient so that the patient cannot drop. Preferably this should end in a seat for the patient because sitting in a rope soon becomes very uncomfortable. The depth must be limited to 9m and that is achieved by putting a mark on the rope 9m from the patient and keeping the mark at the surface. The patient must be over weighted, and it is a good idea to put a weight on each ankle so that his or her legs do not float up. An attendant is needed in the water to watch the patient. A communications system is needed. The simplest communication system is that the patient talks into the full face mask. This is easily understood by the attendant. The attendant must have some sort of slate to write on so that he can write messages for the patient to read. When information has to be taken to the surface the simplest way is for the attendant to signal the surface for another attendant to be sent down. When he or she arrives, the first attendant goes up to the surface and gives the message to the supervisor.

The equipment SPUMS has is a Scuba Pro Visionnaire full face mask (Figure 5) and the hose comes off the top of the mask. It has to be led down the patient's back and put under the weight belt so that if the patient does convulse it is not going to be dislodged by the patient thrashing about. With the Visionnaire full face mask the glass acts as an inhalation diaphragm. The inboard end of the equipment is preferably a 'G' size cylinder of oxygen which will last for a full treatment, and an oxygen regulator which has to be adjusted to as near 100 psi as possible. Anaesthetic regulators are set to 60 psi and can seldom be adjusted above 80 psi. The oxygen hose must be clearly marked in feet or metres so as to control the ascent. There has to be a tender for the

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Figure 5. Diver in Visionnaire full facemask ready for in water oxygen recompression.

oxygen hose, to keep an eye on the patient. There has to be a minimum of a spare tender. Someone has to keep records of times and depths. So there has to be a minimum team of 4. Then all that is needed is 9 metres depth of water. This can quite often be found alongside a jetty, and if not, one has to take the patient out to sea.

The patient is put on oxygen. The face mask must be fitted tightly to the head, because if it is not tight water gets in and that is uncomfortable and may be dangerous. The attendant is kitted up breathing air, the patient is lowered to 9 m with the attendant alongside him. The patient stays at 9 m for 30-90 minutes depending on the progress of his decompression sickness. If it was a pain only bend and it is completely cured by 30 minutes, the patient may start the ascent. If the patient has neurological decompression sickness and is completely cured by 30 minutes, he should be kept at 9 m for at least another 30 minutes. The ascent rate is either 1 metre every 12 minutes or, what is fractionally slower, 1 foot every 4 minutes. These rates give ascent times of nearly 2 hours, so it is a short oxygen treatment.

If the oxygen runs out the patient is brought straight to the surface because the whole object of the exercise is to exclude further nitrogen loading. The patient must not be given air while under water. Once the treatment is completed the patient is given oxygen by mask for alternate hours for the next 12 hours.

Hyperbaric oxygen in the water is an emergency treatment for use in warm water in places where a chamber is more than 6 hours away. I have no intention of promoting it as anything other than a second best treatment compared with chamber treatment. However, it is far better for the patient to be treated promptly than to have long delay. I am unaware of any cases who have been made worse by this treatment. There are sufficient people who do not approve of in-water oxygen recompression to make it fairly certain that should anyone have been made worse the word would get out.

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