of great value to all divers, not merely those in the USA. As is true also of efforts in Australia and New Zealand, the scheme also collects non-fatal Incident Reports. These will be co-ordinated with the DAN records to gradually build up a significant data store. It is hoped that future reports will seek to close one gap in the present tables of information, the depth of the incident. It has been shown in both Australia and New Zealand that many fatalities occur at or near the surface, the water/dive depth not necessarily being a critical factor.

Please support your local Incident Scheme. Something you report could save a life.

TABLE 2

Stated Experience of Scuba Diving Fatalities

	1970	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**
Inexperienced	48	47	33	43	54	39	45	37	44	47	52
“Experienced”	52	63	67	46	46	61	55	63	56	63	48
Not Stated	10	2	9	36	44	31	47	2	16	20	9
TOTAL	110	112	119	125	144	131	147	102	116	130	109

HYPOXIA IN OUT-OF-AIR ASCENTS
A PRELIMINARY REPORT

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In December 1977 the Undersea Medical Society (UMS) convened a workshop on Emergency Ascent Training in Bethesda, Maryland, supported by a National Oceanic and Atmospheric Administration (NOAA) grant. At the conclusion of the workshop, it was found that rather than answering many of the questions, the conference had served rather to define those areas requiring further investigation.

It was suggested by one of the participants that critical levels of hypoxia were likely to occur in the course of any emergency ascent arising as a result of an out of air situation and that this hazard might well rank with that of air embolism. Surveys of deaths occurring while scuba diving reveal variable numbers of drownings. The Rhode Island survey (2) shows 70% of scuba deaths due to drowning, our own statistics in Ontario (3) indicate a lower figure of 66%. Detailed examination of these reveals that many drownings are secondary to embolism. Others may have been secondary to this or other difficulty but missed due to improper autopsy technique, or no autopsy, but there remain a number of these deaths which may well be due to hypoxia before the surface is reached. Whatever the cause, failure to reach the surface has been uniformly fatal in our experience. (Table 1)

The majority of the participants were sceptical, but the concept appeared to merit further investigation and this paper is devoted to an initial hypothetical analysis of this problem and a preliminary report of a series of experimental ascents to test the hypothesis.

TABLE I

OUTCOME OF 37 SERIOUS DIVING ACCIDENTS

TOBERMORY 1974 - 1982

	Deaths	Survivors
Failed to surface	12	0
Surfaced	3	22
Totals	15	22

These cases include cerebral air embolism (CAE) and carbon monoxide (CO) poisoning.

PROBLEM ANALYSIS

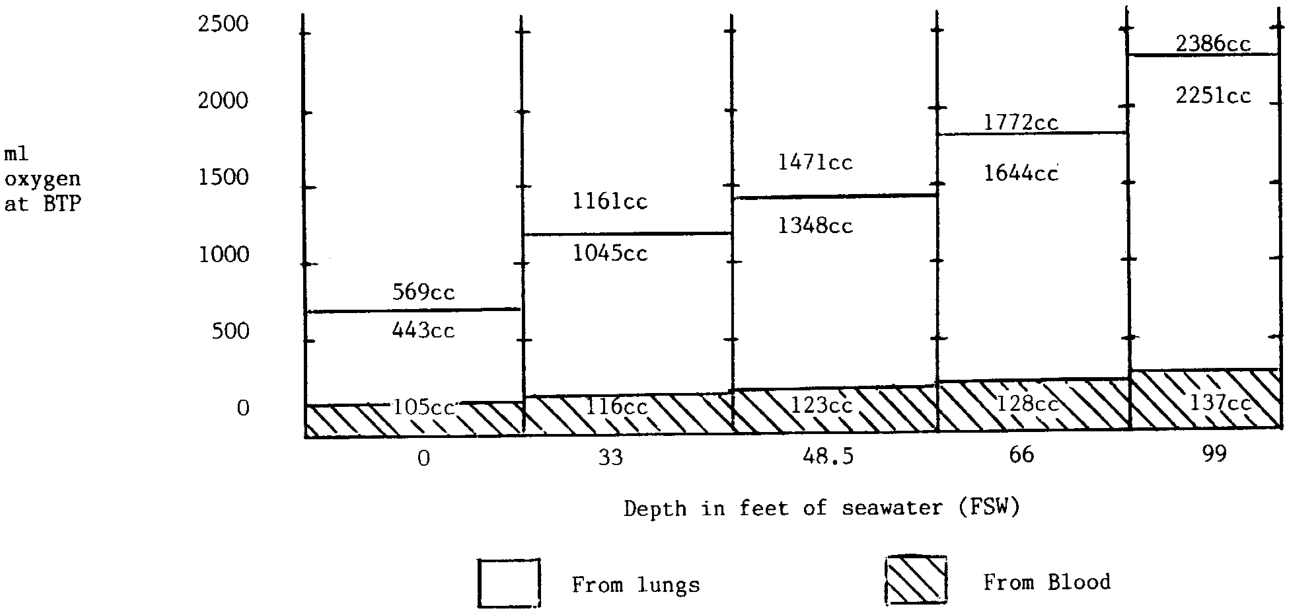
If we analyse the situation which exists when a diver runs out of air, we can derive his available oxygen (O2), the projected O2 cost of the ascent and then predict the course of his PaO2. Certain conditions must be assumed for this exercise and we have selected the following.

Our diver is an 80 kilo man, reasonably fit with a vital capacity predicted for 184 cm height and 32 years of age, 5.7 litres.(4) We have further assumed that he has a haemoglobin (Hb) of 15.0 gm% and a total blood volume of approximately 6 litres represented by 2042 ml oxygenated blood and the balance mixed venous.(5)

The out of air emergency is assumed to occur while the diver is swimming actively at a level which has produced a steady state and that the lack of air is discovered by the diver, when he attempts to breathe in following a normal expiration. He is assumed to be in standard sport diving dress (wet suit and fins).

TABLE II

OXYGEN AVAILABLE AT VARIOUS DEPTHS



Oxygen available has been calculated using a starting PaO2 of 116 and assuming lung volume to be FRC (2.9 litres).

The diver is presumed to respond to this emergency within 3 seconds by initiating an ascent remaining neutrally buoyant throughout. Whatever breathing routine is employed during the ascent, the hypothetical diver unloads sufficient gas to stay at his FRC (2.9 litres).(4) We neglect the decrease in this value which has been shown to occur with head up immersion due to the chest wall pressure gradient. Most authors have shown this to be of the order of 30%.(6)

Table II outlines the oxygen (O2) available on the bottom for the depth or pressures indicated.

Work by Lamphier (9) and other authors has shown that the optimum swimming rate for a diver with fins is approximately 90 feet/min, and that at this rate the O2 consumption equals 1.5 litres/minute.

Using the total O2 figures from Table II, less the amount lost in expired gas as the diver ascends, we can calculate the depth at which the diver's PaO2 will cross the critical value of 40mm which in most of us would result in abrupt loss of consciousness during such as ascent.(Table III) It is at once apparent from this bar graph that the critical situation will always arise close to the surface but that in all cases where the ascent is commenced from depth of more than 45 feet sea water, it takes place before the diver can hope to breathe surface air.

One of the conditions we assumed for this ascent at its outset was neutral buoyancy, so if the hypothetical diver loses consciousness he will not continue to ascend, rather he will lose his regulator and take in water, thereby simultaneously drowning and becoming negatively buoyant making effective rescue and survival improbable.

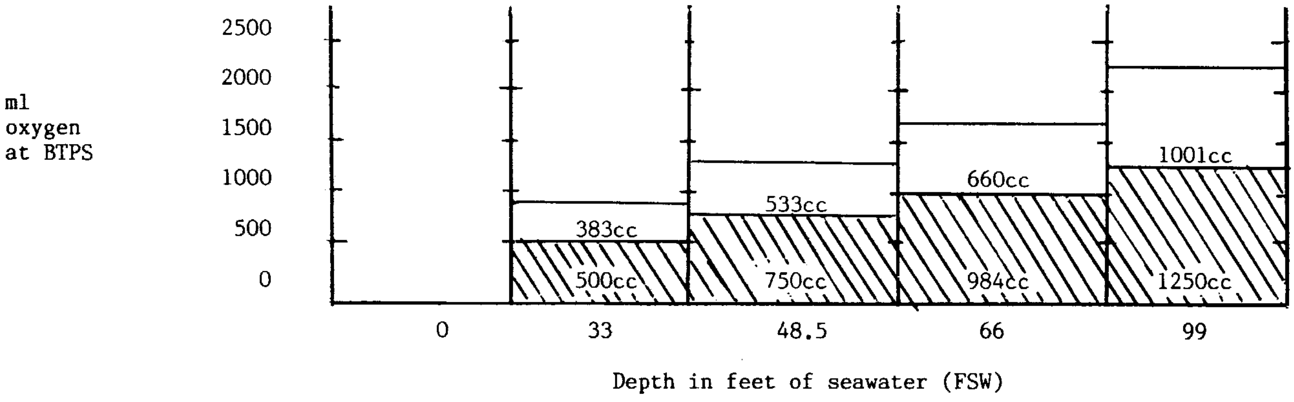
METHOD

To test this theoretical case, two divers were subjected to repeated ascents in circumstances as close to those specified as it was possible to approach with reasonable safety.

Employing a double lock chamber the divers were in turn taken to the test depth where they worked on a bicycle ergometer for a period of 5 minutes at light load to achieve steady state. The load selected was comparable to swimming at 75 ft/min and was a comfortable one. At a prearranged signal the diver was switched to a very limited volume partial rebreathing circuit (see Figure 1) and 3 seconds later the ascent commenced at as near 99 ft/ min as possible. When the ascent began the diver increased his exertion to a level which had been determined by closed circuit spirometry to represent an O2 consumption equal to the cost of ascent while neutrally buoyant.(7) There is great merit in the argument that in this situation the diver would be attempting considerably greater speed but we selected this speed because it is the most efficient with regard to time and O2 cost. O2 cost becomes increasingly exponential with speeds above 100 ft/min and thus the effect would be to bring on critical hypoxia at greater depth albeit more rapidly. During the ascent the diver had two simple tasks, first to keep his output or speed constant and second, to produce a regular repetitive tapping with a metallic object.

TABLE III

OXYGEN COST OF ASCENT



	0	33	48.5	66	99
Depth of Exhaustion	0	0	0	2.5	16.0
Depth PO_2 = 40 mmHg	0	N/A	6.0	11.0	27.2
Depth PO_2 = 70 mmHg	0	N/A	11.0	16.0	31.0

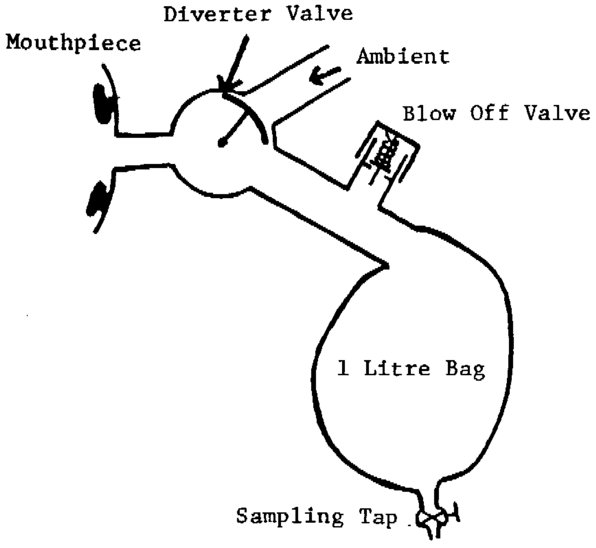
Lung Volume assumed to be FRC (2.9 litres)

▨ O_2 consumed

□ O_2 lost to expansion

Failure or irregularity in the performance of either of these tasks was noted against depth by an outside observer while the tender in the lock was prepared to close the valve on the rebreather bag to retain an expired gas sample at the failure point and administer O2 if necessary.

FIGURE 1



The partial rebreathing circuit was employed because of the potential for embolization due to small airway closure if continuous exhaling routines were used. It also served to provide a source of expired gas samples, which due to the rapid rebreathing could safely be considered to represent an end expired gas sample essentially in equilibrium with alveolar gas tensions, and consequently gas levels, with only a slight lag.(8)

In addition to direct equipment and physician availability, the main lock of the chamber was held at 200 feet throughout so that a very speedy dive to 165 feet could be effected if required.

Unlike the theoretical diver the subjects had the advantage of retaining 1.0 litre of their expired gas and being able to rebreathe it. It is difficult to calculate accurately how great this advantage was in ml O2, but it essentially increases the FRC by 1.0 litre and consequently reduced the loss due to expansion during the ascent. It gave the experimental subject a significant edge over the hypothetical diver.

When the end point was reached, as determined by complete failure of one or other of the primary tasks or in one case, because of unconsciousness, the tender would trap the last expired gas sample in the rebreather bag by closing the valve and the gas was then analysed at the surface for O2 by Ohio O2 meter model No 601 with modified scale expansion and for CO2 by modified Campbell Haldane apparatus. The results, corrected for depth and BTP, are

TABLE IV

RESULTS OF TEST RUNS

(Average of 3 runs at each depth)

Starting depth and subjects	30R&H	45R	45H	60R	60H	90R	90H
Depth difficulty began	N/A	10	15	20	21	34	7
Depth terminated	0	4	7	12	8	9*	10
pO_2 mmHg at termination	N/A	48	48.4	60	55	47	56
pCO_2 mmHg at termination	N/A	47.7	53.5	72	81	71	58

* went unconscious

Subjects H & R

shown in Table IV.

DISCUSSION

Although the number of ascents and subjects is small, the results showed that the subjects became critically hypoxic before reaching the surface in all cases starting deeper than 45 feet and that the depth at which this occurred, moved down slightly with deeper dives in accordance with the prediction. We made no attempt to predict the course of the CO_2 and were surprised at its marked rise in many of the ascents. This rising CO_2 would enhance O_2 release from the haemoglobin, but would add to the cerebral dysfunction caused by the hypoxia.

The subjects were aware of fixation of purpose during the latter phases of all runs and this parallels reports by divers who made such ascents. Some of these have reported amnesia for the final portion of the ascent consistent with critically low O_2 levels.

Fortunately most sport divers at this time are using buoyancy compensators or other flotation devices which will passively expand as the diver ascends, eventually resulting in buoyancy assistance during the ascent without specific action on the part of the diver. This fact has probably saved more than a few lives.

Unfortunately it is required that the diver accomplish some variable portion of the ascent for this to occur and hypoxia comes on without warning so that there may be no opportunity for the diver to take action to alter his buoyancy at the critical instant.

The O_2 cost of the same ascents, accomplished at the same speed by buoyancy alone, is much less.

The surplus O_2 provided by this method is an obvious advantage which must be weighed against increased risk of air embolism or decompression sickness due to uncontrolled ascent or inappropriate techniques. We believe training can minimize these.(9)

CONCLUSION

This information clearly needs to be taken into account when devising responses for the out of air situation. The diver needs to ensure that he has the ability to render himself positively buoyant in any ascent which may result in hypoxia or loss of consciousness from any cause. This has been borne out by the statistics in our experience.(Table 1)

Alterations in the amount of O_2 available can be achieved by increasing the lung volume during ascent, decreasing exertion, and use of alternate air supplies. We feel that further study is needed in this area to clarify the issues involved. Ascents from depth to 120 feet are planned with a refined protocol.

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This paper has been in the hands of the SPUMS J since March 1983. A letter in September 1984, asking Dr Harpur whether the long interval had altered his views and whether he had any objections to its being published produced the following reply.

Tobermory Medical Clinic
PO Box 220 - NOH 2 RO
Tobermory, Ontario

17 September 1984

To answer your questions quite simply, no, I have not encountered anything which would persuade me to alter my views since that paper was completed, and no, I do not have any objection to it being published. Our experience since that time, has if anything reinforced the views expressed, and I am happy to report to you that whether entirely due to the adoption of the principles outlined in the Ascent Protocol you published earlier (SPUMS J 1982 Oct-Dec: 32-38), or to improved instruction, we have seen a drastic reduction in diving accidents and fatalities in our particular region over the past three years. We were reluctant at first to call this a definite trend, but it has been consistent enough that we are now quite certain it is. This has had the somewhat unfortunate effect of reducing our opportunities for expanding clinical experience, as the bulk of the difficulty now encountered centres around sinus and ear squeeze.

Yours sincerely

GD Harpur

We are sure that all our readers would like to be able to quote similar statistics for their region!

Dr Harpur recommended (SPUMS J 1982 Oct-Dec: 32-38) a continuous breathing cycle for out of air ascents. The points are

1. DO NOT remove the regulator from your mouth unless you have another to replace it with, or in cases of entanglement. *The regulator provides a safety valve and a possible source of air.*

2. Continue to attempt to breathe in and out at all times even if out of air or without your regulator. *This ensures an open glottis and larynx and minimises the chance of small airway closure.*

3. Make certain you are positively buoyant by inflating your buoyancy compensator or dropping the weight belt or both. *This guarantees that you will reach the surface despite hypoxia.*

Dr Harpur also emphasised that CPR training was the most critical factor, *in the accidents in the Tobermory region*, in determining the outcome if the diver surfaced. Good dive organisation ensured rapid response and prevented incidents from becoming complicated.

DAN (DIVERS ALERT NETWORK) AUSTRALIA

Robert Sands

The DAN organisation provides a valuable service in the United States of America. It arranges transport for injured divers, coordinates evacuation procedures, and gives state of the art advice to Medical personnel when emergencies do occur.

As well, the service collects accident details and statistics and after considering the material makes observations and gives advice to relevant authorities in a non judgmental manner. It also works to keep the keen diver educated in diving safety and first aid techniques.

As this service consumes a large amount of money to operate it and is no longer funded by the Federal Government it looks to individuals, organisations and business corporations for the funds.

Because the makers of the Bendeez Adaptor are considering becoming a corporate sponsor in the United States and the Directors of Paracel Holdings Pty Limited (the makers of Bendeez) were impressed with the DAN organisation they offered to conduct a small survey to find whether a similar organisation was indeed possible in Australia. It was suggested that if so, it would have an association (non-profit) with the US DAN for mutual benefit (data exchange etc).

The survey conducted was at a number of levels. For example, Diving Medical Specialists with a high media profile were contacted and their views sought on DAN's viability and their own participation if DAN was set up in Australia.

As well, the Instructors from the major teaching groups were asked their opinion and their participation. So too were dive store owners and finally ordinary divers were asked whether they would subscribe to DAN in a similar fashion to their American 'cousins'

It is significant also that a number of very large Australian companies indicated that they would support an Australian DAN.