other questions are being explored, and hopefully answered, several important changes can be made in current practices without hazard.

1 Instructor organisations can standardise their teaching

2 Regulators can be left in the mouth and attempts at inspiration made during ascent which will:
   a reduce tendency to panic
   b provide air from the tank thus delaying onset of hypoxia
   c reduce any chance from alveolar rupture due to trapping.

There remain other problems, but perhaps from this workshop there will be the beginnings of an organised effort to eliminate these gaps in our knowledge so that some definitive solutions can be found.

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FIRST AID PRIORITIES FOR DIVERS THE TOBERMORY VIEWPOINT

G. Harpur

Reprinted, with minor changes (metric depths and weights), from *SPUMS J* 1982; 12 (Oct-Dec.) 32-38

Due to the large number of divers attracted to the Tobermory area by the clear waters and abundant marine artifacts, we are provided with many opportunities to examine those events surrounding diving accidents which influence their outcome. In the past year approximately 30,000 dives were carried out, principally between the 24th May and the Thanksgiving weekend in October, by some 7,500 divers of whom 30% were student divers on their initial open water experience. Since 1974, there have been 36 accidents resulting in major injury to divers as well as countless minor incidents with less serious sequelae. In this paper I intend to present a review of the more serious incidents and accidents with particular attention to those factors which contributed to the serious or fatal outcome.

Our figures indicate that on any given dive in the last two years, the diver's chance of being injured was 0.04% and of being killed was 0.003%. These figures do show a higher incidence than is reported elsewhere, e.g. the Rhode Island surveys, and may reflect the effects of cold water and the high proportion of novice divers. Training accidents have been rare, with only 1 fatality and 2 serious incidents occurring in the past 7 years.

TABLE 1

FACTORS RESPONSIBLE FOR INCIDENTS WHERE A DIVER FAILED TO SURFACE OR SURFACED WITH ASSISTANCE

Diver fitness

Training

- None or taught by a friend
- Diving alone
- Improper response to :-
  - freeze-up
  - emergency ascent
  - buoyancy control
  - shallow water blackout

Psychological State

- Unfit
- Temporary conditions
- Pre-existing long term conditions

Medical Conditions

- Temporary
- Pre-existing long term

Equipment

- Inadequate
- Malfunction

Rescue

- Poorly organised or not plan
- Improper technique

There have been 16 deaths in the period 1974 to 1981, out of a total of 36 serious accidents. Of these deaths, 11 died before reaching the surface, 3 died after reaching the surface but before reaching the recompression facility and 2 died after completing an initial treatment table. The remaining 20 divers all survived and were entirely intact, so far as could be clinically determined, after one or more treatment runs. There were no survivors who sustained any long term injuries as a result of their accidents. This type of sharp division is probably unusual and can be most likely explained by the unique character of our situation in Tobermory. Most of the diving takes place within the confines of Fathom Five Provincial Park and this area is controlled by both Ontario Provincial Police (OPP) and Park staff routinely, so a very rapid response to any accident is possible. The average time from the victim arriving at the surface until being placed back under pressure, when indicated, is between 30 and 40 minutes. This organisation also permits a very detailed investigation of each incident and accident to be carried out at the same time as the victim is being treated. Park staff and OPP dive team member conduct interviews with other members of the diving group. In more serious cases, exhaustive studies are conducted on the equipment and air supply, with the assistance and such technical support as Defence and Civilian Institute of Environmental Medicine (DCIEM) and the Centre of Forensic Science in Toronto.

If we consider first the group of divers who failed to make the surface on their own, we can divide them into subgroups according to the various factors which accounted for this failure in each case. In some of the accidents, more than one of the factors listed in table 1 may have been present. The following brief case histories serve to illustrate these points.

Diver fitness

TRAINING

Fortunately we have not encountered many cases of diving without formal instruction which have resulted in problems in Tobermory, although these are common elsewhere. The one example we have illustrates a combination of informal instruction, diving alone and inadequate equipment.

DIVING ALONE

P.H., a 26 year old male, who had just completed his PhD. in Maths and Physics, and who was a self taught skin diver, was free diving to 15-18 m (50-60 ft) depth in an area off the shore of Georgian Bay which had a flat bottom, sloping gradually to depth in excess of 30 m (100 ft). He had no buddy, but there were several groups of scuba divers in the same general area. His friends on shore wandered away for a period, as they were accustomed to his being out for periods up to one and a half to two hours. He was not on the shore or visible in the water when they returned. After a period of confusion and trips to his car 1 mile away, the alarm was raised. It was now dusk. His body was located the next morning by OPP divers in 21 m (70 ft) of water. It was on the bottom with 7.3 kg (16 lb) of lead in place, a full wet suit, mask and flippers and no buoyancy device. Another weight belt, visible from the surface, with 8 kg (18 lb) of lead on it, lay nearby. Autopsy determined the cause of death to be drowning. His lack of adequate training undoubtedly left this diver unaware of how rapidly shallow water blackout occurs, and his lack of a vest reduced his options.

We have not been able to document a single case in which equipment malfunction directly caused a diver's death or injury. It has always been the diver's response to the problem which results in the pathology. Recognition of the malfunction and effective management of it are part of good diver training. The following cases illustrate areas where the job is still being inadequately done.

INAPPROPRIATE RESPONSES:
FREEZE-UP

Regulator freeze-up is a common event in cold water, which is to say in all water deeper than the thermocline in Canadian lakes at any time of the year. Proper training should reduce unnecessary use of the purge button, anxious panting and heavy exertion which encourage this problem. All students should be aware of the problem, exposed to it and taught how to recognize it and how to respond appropriately. That is by breathing off the free flowing regulator to the surface. Failure to do this has been the initiating event in several incidents, two of which resulted in fatality.

In the first of these, the individual who died was an innocent bystander.

J.M. was an 18 year old male diver who, after qualifying the day before, was persuaded to participate in a badly conceived dive to 21 m (70 ft) off Flower Pot Island. Four divers took part. Two had previous experience to 21 m (70 ft) in warm water, and formed one buddy pair. J.M.'s buddy had one previous dive to 30 m (100 ft) in cold water. None of the divers were familiar with the site. No shot line was dropped to confirm depth, despite the fact that depths in excess of 90 m (300 ft) are encountered in this area.

Difficulty with buoyancy control was encountered by all the divers during the descent as they had all weighted to neutral trim at the surface and failed to anticipate the effects of wet suit compression. This resulted in a rapid descent and the divers found themselves very unexpectedly at 27 m (90 ft), just 6 m (20 ft) off the bottom in clear 4°C water.

At this point, one of the pair of warm water divers encountered a free flow probably secondary to anxiety and overbreathing. He abandoned his regulator and attempted buddy breathing but was unsuccessful due to numb lips. His buddy now abandoned him, ascending rapidly. J.M.'s partner, the most experienced diver, took over. The three remaining divers were on the bottom at 33 m (110 ft) at this point. The CO_2 cartridge, a 25 g size on the victim's vest had been pulled with no apparent effect. (See the later section on vests). The attempts to force buddy breathe the victim were moderately successful. This pair of divers swam up after dropping the victim's belt. J.M. was following in no apparent difficulty. At 15 m (50 ft) the rescuer ran out of air, pulled his reserve and continued up with the victim. J.M. was still in attendance. At 9 m (30 ft) the rescuer completely ran out of air, dropped his weight belt, blew his vest and released the victim who was now positively buoyant. Both divers arrived on the surface where the other diver was waiting. The victim was in fair shape although he underwent prophylactic recompression for possible cerebral embolism at Toronto General Hospital later.

J.M. never arrived at the surface. Lack of planning led to the confusion and delay in the rescue attempts. The body was recovered 4 hours later by OPP divers on the bottom, in full gear with his vest and CO_2 cartridge intact (i.e. not activated). Autopsy showed death was due to massive air embolism. The degree of mask squeeze present suggested that J.M. made a breath hold lunge for the surface when the other divers took off from 9 m (30 ft). His tank contained air and there was no evidence of equipment malfunction.

Although J.M. did not encounter free flow, the failure of the initial victim to deal properly with this event initiated the sequence which led to his death.

The second example illustrates a much more direct effect.

S.G., also an 18 year old male, was making a dive on the Arabia, which lies in 33 m (110 ft) of water. He too was a low time diver, but did have several hours of post certification diving at depths of up to 12 m (40 ft) in cold water. The temperature at 33 m(110 ft)was 4°C as usual and the visibility 12-15 m (40-50 ft) in low light. He encountered a free flow at 30 m (100 ft) early in the dive, and abandoned his regulator. His buddy commenced buddy breathing with him, but S.G. refused to return the regulator. The buddy dropped his belt, activated his CO_2 vest and swam up, dragging the victim, he thought, by the regulator, When he arrived on the surface, S.G. was not with him. The body was recovered several hours later in full gear and with an intact CO_2 cartridge. Autopsy showed death had been due to massive air embolism to all major vessels, with damage to both lungs. Panic induced by an inappropriate response and the surprise of an unfamiliar problem had claimed another victim.

There were also many minor incidents which avoided a similar conclusion only by chance. One, which was somewhat amusing, involved a fellow and his girl in 9 m (30 ft)of water. The girl encountered a free flow and abandoned her regulator. He being chivalrous, gave her his. She refused to relinquish it. As in the last case, he bounced to the surface, dragging her with him, but in this case she was unharmed. The abrupt development of a romance-shattering insight was the only damage done.

The major problem in all these cases arose because of an inappropriate response i.e. abandoning the regulator. This indicates a flaw in basic training. Good free flow simulation is possible. OUC have recently published a modification to a standard scuba set, devised at Tobermory, which will permit any student to be exposed to this problem and its management, in the safety of the pool.

INAPPROPRIATE RESPONSES : EMERGENCY ASCENT

Even with the best of training and planning and equipment, if one dives long enough one will encounter an out of air situation, more frequently if one neglects any of the foregoing.

The inadequacy of the responses currently being taught for use in this situation, are illustrated by the next series of cases.

J.K. was another 26 year old male diver. The frequency of this age and sex combination begins to look like an ill omen. He was performing an emergency ascent from 9 m (30 ft) in open water as part of his graduation exercises. The drill to be followed was :

1 remove the mouthpiece
2 undo the weight belt and pass it your buddy
3 swim up, humming constantly, with the instructor and flare at about 1.5-3 m (5-10 ft).

J.K. commenced his drill but fouled up at 2, when he undid his tank strap. He replaced his regulator, refastened his strap and after a brief rest, started again. He completed the exercise correctly and was observed to be exhaling, presumably by humming, throughout the ascent, by his instructor. At the surface he was immediately asked how he felt. He replied, “I feel fine”, just before passing out and convulsing. CPR was effectively applied and he was evacuated to the beach and subsequently to the hyperbaric chamber, in approximately 25 minutes, where an immediate table 6A with extensions was commenced. He recovered spontaneous respiration and circulation after drainage of bilateral pneumothoraces, and remained stable despite repeated recompression. He died 4 days later of brain infarction. Examination of his equipment and gas analysis revealed no problems.

J.K. had approximately 10 litre lungs. If we assumed that he near filled his chest before his attempted ascent, the outcome is easy to explain. Humming does not permit a lot of air to escape. The amount necessary to produce a good hum can be as little as 50 ml/second. A hard hummer can get rid of 500 ml to 1 litre/second, but averages are probably around 250 ml/second. From 9 m (30 ft) to the surface, J.K. had to clear 9 to 10 litres if he was to avoid disaster and his ascent time was 6 to 7 seconds. Humming obviously could not do the job. Unfortunately the lungs provide little warning of the impending disaster as evidenced by his “fine”. The tragic part is that his unimpeded airway had the capacity to handle flows in excess of 10 litre/second, more than 6 to 7 times his requirement. The obvious solution is to teach an ascent technique which keeps the airway open. (See continuous breathing cycle ascent below).

Probably the commonest emergency ascent technique taught is the continuously exhaling pattern. This mode of ascent was definitely used in 8 of our embolism cases who survived, in one of the fatal cases for certain, and it is highly probable it was the technique used in 4 others. This constitutes about 60% of the fatalities and about 75% of the casualties, due to ascent technique.

The case of diver T.R., a 42 year old male, assistant diving instructor illustrates this very well.

T.R. had completed a well organised dive with his club on the Arabia and was making the ascent from 33 m (110 ft) when he decided that since he was ascending a little faster than the normal 18 m (60 ft) a minute, he should probably do what he taught his students to do during fast or emergency ascents i.e. exhale continuously.

This was the last thing he could recall until he came to in the hyperbaric chamber some hours later. He had arrived at the surface unconscious and not breathing, brought up by his own vest due solely to vest expansion. He had some frothy red sputum coming from his nose. His group followed their emergency training and commenced artificial respiration (EAR) with the victim on a 20° head low slant and transported him to the chamber. On arrival there he was breathing spontaneously, coughing up some bloody sputum. He was still very obtunded, responding only to deep pain. Rapid recompression on a table 6A resulted in dramatic recovery within 15 minutes. He was confused for the first one and a half hours after full recovery of consciousness. He kept asking how he could possibly have embolised, as he was so positive about his decision to exhale. We reassured him that although many would doubt him, we did not and explained the mechanism of small airway closure to him and the hazards of exhaling ascents. The sad part is that this diver had adequate air supply and stopped breathing only because he was misinformed.

The degree of embolism sustained in this case was obviously slight and this is typical of the injury which results from low volume air embolism. The embolism does not usually kill directly, but does alter consciousness and lead to drowning. These cases are often missed at post mortem as not many pathologists are well versed in the mechanics of diving injuries. This problem, like that created by the humming ascent, is avoided by the continuous breathing cycle ascent protocol.

INAPPROPRIATE RESPONSES :
BUOYANCY CONTROL

In many of the cases where the diver died, the cause of death was drowning and the embolism or hypoxia or fatigue which led to this outcome were not in themselves serious. In these instances a failure to get to the surface or a failure to remain there, was the critical factor in determining the outcome. Many critically injured divers survived because they reached the surface. All of those who remained on the bottom or returned to it, died.

This underscores the importance of the diver making certain that he will continue to ascend even if he loses consciousness. None of the divers recovered from the bottom had dropped their weight belt, and none had deployed the CO_2 cartridge or otherwise fully inflated their vest.

The case of P.H. cited earlier, illustrated the effects of hypoxia in free diving. Many scuba divers fail to appreciate that once they are out of air they too can become critically hypoxic during ascent for the same reasons. Calculations show that a diver who runs out of air and then attempts to swim up with no assistance from vest or from dropping a weight belt runs a significant risk of abrupt loss of consciousness during the ascent if he starts deeper than 15 m (50 ft). In trial runs from 18 m (60 ft) in the chamber at Tobermory, while exercising at a level equivalent to such a swimming ascent, two subjects were unable to complete a simple secondary task all the way up, both becoming confused at depths greater than 1.8-2.1 m (6 to 7 ft). A repeat run from 27 m (90 ft) resulted in one subject getting into difficulty with confusion at 6.3 m (21 ft), the other at 4 m (13 ft). Such confusion under water could result in loss of control and breath holding, with subsequent embolism or aspiration of water and drowning.

A good example of this is the case of L.C. a 27 year old diver on her first night dive in the company of an older more experienced diver. The dive was planned to 9 m (30 ft), but the area of the dive included depths to 27 m (90 ft). Both divers were weighted for a neutral trim at 5-6 m (18-20 ft) with 5.5 and 6.3 kg (12 lb and 14 lb) lead respectively. Some incident led to both women embolising and neither shed her weight belt or inflated her vest, but one surfaced, the other, L.C., was recovered the following day, having drowned following a minimal embolism. I wish I could say the other survived, but she did not for a series of reasons I shall deal with later, but she had a chance, L.C. had none.

Psychological fitness

Many of the incidents, especially those which commence with free flow, indicate that the diver involved was under excessive pressure at the time of the incident.

Most frequently this stress appears to originate in peer pressure. The low time diver attempts a dive which takes him out of his depth and experience in order to be one of the group and prove that he can hack it thus setting the stage for tragedy. As this factor is apparent in many of the cases cited, I will give no specific example.

This same problem, diving while under excessive duress, has led to two cases of spurious decompression sickness. Both of these cases presented as type two decompression sickness but the findings were inconsistent and the complaints variable. Resolution of one case required a sham chamber treatment with descent to 1 m (3 ft) on compressed air resulting in an abrupt and total resolution of all symptoms and signs.

Medical conditions

TEMPORARY

Medical fitness or rather the lack thereof has been a significant factor in both incidents and fatalities. Temporary disability of minor degree has served as the trigger factor in several cases and the commonest example is difficulty with ear clearing. It would appear that we are not doing a very good job of training people in this area. We conducted a survey of novice divers during the summer of 1978 with the results shown in Table 2.

TABLE 2

DAMAGE TO THE EARS OF 186 NOVICE DIVERS

No Barotrauma		79
Minimal		29
Moderate		70
Severe		8
(Bilateral)	(11)	

The interesting point about this is that despite the fact the two-thirds had significant trauma to their ears, only one or two recognised this fact.

Most of the problems created by this sort of trouble have been minor. We see a steady stream each summer that we refer to as investors. The people leave home 200 or 300 kilometres away without checking that their ears can clear. They arrive in Tobermory, pay for their charter, rent equipment and get teamed up with a buddy, and still have not checked that their ears clear. Finally at 3-4.5 m (10-15 ft) on the first dive, with all their money and time invested, they discover that their ears are going to be difficult. They proceed to try everything known to God and Man to get those ears to work, frequently winding up in our hands with various types of squeeze or worse.

The effects are not always trivial. There has been one case of a diver, G.P., in whom air embolism resulted from panic at 3-3.6 m (10 to 12 ft) over ear pain. He made a breath hold ascent and became confused with bloody cough and voice changes. Response to therapy was excellent and a modified table 6A resulted in his total recovery.

Most serious problems arising as a result of temporary disability are a result of diving while under the influence of drugs, the commonest being alcohol. The partner in the case L.C. cited earlier, was a 42 year old female, K.C. What event led her to embolise during that night dive was unknown. She came to the surface where she added fresh water drowning to her problems because her face was not supported free of the surface with her weight belt on and the vest was not inflated. She vomited and aspirated during resuscitation attempts. Despite effective CPR and surviving her initial chamber treatment, she eventually died with the following injuries: massive air embolism of the cerebral vessels, aspiration pneumonitis and fresh water drowning. Her blood alcohol was reported as twice the legal limit.

Fatigue, alcohol and decongestants figured in the temporary disability which led to the death of T.R., a 26 year old male diver. T.R. drove up to Tobermory during the night, arriving at 0600 hours having imbibed liberally en route. During his first dive of the day at 1000 hours he experienced difficulty with his ears. So he took a couple of Sudafed tablets. This was his first experience with this particular medication, and for good measure he washed them down with a couple of ounces of rye. Two hours later he made a dive to 12 m (40 ft) for 45 minutes. He made an abrupt swimming ascent for reasons which were never elucidated. At the surface, he was confused and could not stay up, succeeding neither in releasing his weight belt nor in inflating his vest. He subsequently lost contact with his buddy and sank. He was recovered by other divers in a few minutes at a depth of 1.2 m (4 ft). He was unconscious and failed to respond to attempts at resuscitation. The cause of death was drowning secondary to minimal air embolism.

Street drugs probably played a significant role in the death of L.S. This 23 year old diver approached two other divers at 30 m (100 ft) with his regulator out. He took the regulator offered him and took one breath returned it, then refused to take it back. The rescuer had located his octopus and offered the regulator to keep, but it was refused. The victim was now in total panic and holding tightly onto part of the wreck Arabia. The rescuers pried his fingers loose and took him up, squeezing his chest, pounding his gut and doing all the things they had been taught to make him exhale.

Unfortunately an air breathing mammal underwater in severe panic will give you almost anything, his lunch, his blood, but not his air so long as he remains conscious. Thus the diver predictably held his breath and sustained a massive degree of embolism resulting in instant irreversible death. Subsequent investigation showed that hallucinogens and cannabis had both been in use. A more effective job of educating sport divers to the hazards of diving while impaired physically, emotionally or pharmacologically is the only thing that will reduce the frequency of these occurrences.

LONG TERM PRE-EXISTING CONDITIONS

The presence of a long term pre-existing medical condition which should contraindicate diving is becoming alarmingly common. What is most disturbing about this is that many of these divers with a history of epilepsy, or asthma, have reported their illness to the physician who did their screening physicals, required to enter Scuba training by most agencies, and were cleared as completely fit to participate in the sport. The consequences of this are well demonstrated by several incidents. I will cite two.

G.B. was a 42 year old diver with a long history of epilepsy which had been under control for more than 20 years, but which still required that he take Diazepam (Valium) on a regular basis. During a dive to 15 m (50 ft), off Lighthouse Point in the Tobermory harbour area, he lost consciousness during ascent while separated from his buddy. Fortunately he was positively buoyant and continued to the surface. His luck at the surface was good as he popped up under the nose of some well trained people who cleared his airway of vomitus and administered effective CPR, which was required. When he arrived at the Hyperbaric facility 20 minutes later he was still comatose and requiring AR, but now had spontaneous heart action present. After 15 minutes at 40 m (165 ft) he showed no signs of recovery. When placed on a breathing mixture of 50% N_2 and 50% O_2 he responded rapidly. Within 5 minutes he was awake but struggling and confused. He remained confused for 4 hours while an extended table 6A was carried out. He then abruptly recovered totally except for a short period of amnesia surrounding the dive. The difficulty with short term memory persisted for several days. His subsequent course was one of total recovery with no sequelae. He no longer dives.

The second case is that of a 59 year old male, V.K., who had pre-existing arteriosclerotic heart disease with a rhythm disturbance, requiring medication, and chronic obstructive lung disease of moderate degree, also requiring medication. At 33 m (110 ft) on the Arabia this diver became stuporous and confused, but was brought up under control by his smaller female buddy in a truly remarkable display of good diving skills effectively and calmly applied. He was coughing bloody sputum and unconscious at the surface requiring EAR. Recovery was rapid but complicated by aggressive behaviour and confusion adding to the problem of his management. At our unit he presented as a case of definite pulmonary barotrauma with bloody, frothy sputum and of fresh water near-drowning of significant degree superimposed on the original maladies. He was hypoxic and confused to begin with. This had been clearing during evacuation and with O_2 and a head low position continued to do so. He had no pneumothorax. However X-rays confirmed the presence of near-drowning and the pre-existing emphysema. As he was improving he elected not to use the chamber in the face of the serious pre-existing disease. Had he been worse or deteriorating our hand would have been forced. He subsequently made a full recovery. I am sure the possibility of a fatal outcome was not missed by much.

To reduce this sort of problem we have just drafted a short article outlining the hazards of scuba diving and listing the factors to be looked for during medical examination to determine fitness for the sport. This is to be reproduced in the Journal of Family Medicine and the Medifacts tapes system, which should bring it to the attention of a majority of primary care physicians in Canada.

Equipment

REGULATORS

Many of the cases already cited, illustrate equipment shortcomings. Regulator freeze-up can be managed. While it cannot be completely prevented by current single hose designs, many companies have produced products which are more resistant than others. To achieve low breathing resistance, high peak flows are required. Many designs have pursued this goal, neglecting the fact that these higher flow rates imply greater adiabatic cooling and therefore greater risk of freeze-up. Divers should be made aware of those designs which best meet both criteria such as the excellent line by Sherwood which we have found very freeze-up resistant.

CO_2 VEST

In cold water the performance of these vests at depth is pitiful (Table 3). Below 18 m (60 ft) CO_2 vests are wholly inadequate in our 4°C waters, even with the largest of cartridges. A vest can be used as a last resort air supply if fitted with the right mouthpiece and if the skill is practised, but if it is full of CO_2 breathing would of course only hasten your demise. A vest with a power inflator does not ease the problem as the one time you really need that vest is when your air supply has gone.

TABLE 3

CO_2 VEST BUOYANCY

Cartridge size	Lift at 27 m (90 ft) in 5°C water	
38 g	2.3 kg	5 lb
25 g	0.9-1.4 kg	2-3 lb
12 g	0.7 kg	1.5 lb

Two young divers, M.Z. and J.S. died while doing the wreck of the Forest City. These divers were wearing CO_2 vests which at 45 m (150 ft) would provide 0.5 kg (1.25 lb) lift when deployed against net negative buoyancy of approximately 4.5- 5.5 kg (10 to 12 lb). Neither reached the surface nor survived, so the exact role played by this deficiency remains speculative.

The diver T.R. referred to earlier drowned because he failed to inflate his vest on the surface. He was unable to do so because it had a power inflator but he was out of air. It had an oral inflator but he was fighting so hard for breath he could not spare any. It had no CO_2 or alternative last ditch fill system.

The solutions are fairly obvious and simple. An independent filling system for the vest. This should be breathable air if one is diving in cold water deeper than 15 m (50 ft). The training required for safe use of the system should be part of all diver training courses. There is a new inadequacy in equipment which, as far as I am aware, has yet to produce a casualty that I would like to mention in passing.

STABILIZING JACKET

The stabilizer jacket is being widely promoted as the ideal buoyancy device. While it is compact and comfortable in most circumstances, fully inflated many models cause significant restrictions to respiration and a sensation rather like what I have always imagined the grip of an octopus might feel like. These effects could be devastating if experienced for the first time in an emergency situation. Divers should be cautioned in this regard. Details of the restriction to respiration will be included in a study to be published shortly.

MALFUNCTION

Equipment malfunction was an initiating factor in many cases, including J.M., S.G. and L.S. and a complicating factor in others, including R.R. and J.G.

I would like to emphasise that the malfunction per se killed none of these divers. It was their reaction to the malfunction that did.

Rescue

This brings me to the last area of difficulty, the response to the accident by other divers. The most frequent cause of difficulty in relation to technique was with CPR. In three of four cases where divers reached the surface but died before reaching the recompression units, faulty or no CPR was involved. In the case of T.R. loose bridge-work lodged in his throat. The rescuers abandoned CPR on R.R. because the victim vomited. As Resusci-Anne never did that they were totally unprepared. In one case, no CPR was attempted because the victim was cold, blue and had dilated pupils. Most divers could get 2 out of 3 on that test after any dive at Tobermory. In the case of K.C. the initial problems were compounded by faulty CPR, which fractured his ribs and may have lacerated the lungs.

CPR training for divers needs to emphasise that unconscious divers in a head low position almost inevitably vomit, in a passive way and that to save these people you must be prepared to clear the airway, spit out the chunks and keep going. Divers must also be taught that the pupillary signs are totally unreliable when dealing with a potential cerebral air embolism.

Organisation and Planning

The following case illustrates almost every factor I have discussed and many more besides.

J.G. was a 30 year old diver, with low time diving with a group who did not know him or his experience beyond the fact that he possessed a C card. His girl-friend was along as part of the group so the pressure was on as the group decided to dive the Arabia. Dive organisation had been fairly good throughout the weekend, but for some reason which was never clear, it was now let slip. The divers were not in standard buddy teams. On the descent one female diver aborted after crossing the thermocline at 24 m (80 ft) and was left alone on the descending line. J.G. continued down. After completing a part of the distance around the wreck one of the more experienced divers noticed that J.G. was already down to 750 p.s.i and directed him back toward the ascending line. He then turned to signal the rest of the group to follow. The girl left behind was at 21 m (70 ft) and came to the surface with the rest of the group, having encountered no other diver. At the surface, the captain of the charter boat, an interested bystander, pointed out that the group was a diver short and the search for J.G. began. There was no-one who had not already dived. So four of those in the water made immediate repetitive dives, one of them twice, using fresh tanks. Finally 20 minutes later J.G. was brought to the surface, dead. Death was due to massive air embolism of the brain and heart. Subsequent investigation revealed that the diver had encountered a free flow, ascended, embolised and sunk to the bottom where he was found. As a result of the repetitive dives committed, we wound up treating 1 case of type 1 decompression sickness and four cases of missed decompression. I do not believe an additional comment is required.

The dual fatality of J.S. and M.Z. on a dive conducted without a safety diver, reserve air or communication 13 km (8 miles) off shore, illustrated the same deficiencies. The old maxim, plan your dive and dive your plan really says it all.

Lessons for First Aid priorities

In this review of the accidents at Tobermory I have attempted to review those factors which could be altered to improve the situation and prevent the accidents or improve the outcome.

First aid has obviously got to start with training if the figures are to change much. Of 15 deaths, 11 failed to surface which certainly limits one's options in dealing with these accidents. Universal adoption of the continuous breathing cycle ascent protocol below would eliminate most of the air embolism cases. Details of this protocol are available on request.

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 become positively buoyant by inflating your buoyancy compensator or dropping the weight belt or both. This guarantees that you will reach the surface despite hypoxia.

CPR training is the most critical factor to date in determining the outcome if the diver surfaces.

Good dive organisation ensures rapid response and prevents incidents from becoming complicated.

There is no conclusion to this paper, it is in fact merely a beginning in what we hope will become a broader, ongoing review of Canadian diving accidents and incidents leading to improved First Aid for Divers.

HYPOXIA IN OUT-OF-AIR ASCENTS A PRELIMINARY REPORT

G.A.D. Harpur and R. Suke

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In December 1977 the Undersea Medical Society (UMS) convened a workshop on Emergency Ascent Training[1] 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 figures 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 remains 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).

TABLE 1

OUTCOME OF 37 SERIOUS DIVING ACCIDENTS TOBERMORY 1974-1982

	Deaths	Survivors
Failed to surface	12	0
Surfaced	3	22

These cases include cerebral arterial gas embolism (CAGE) and carbon monoxide (CO) poisoning

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.

Problem Analysis

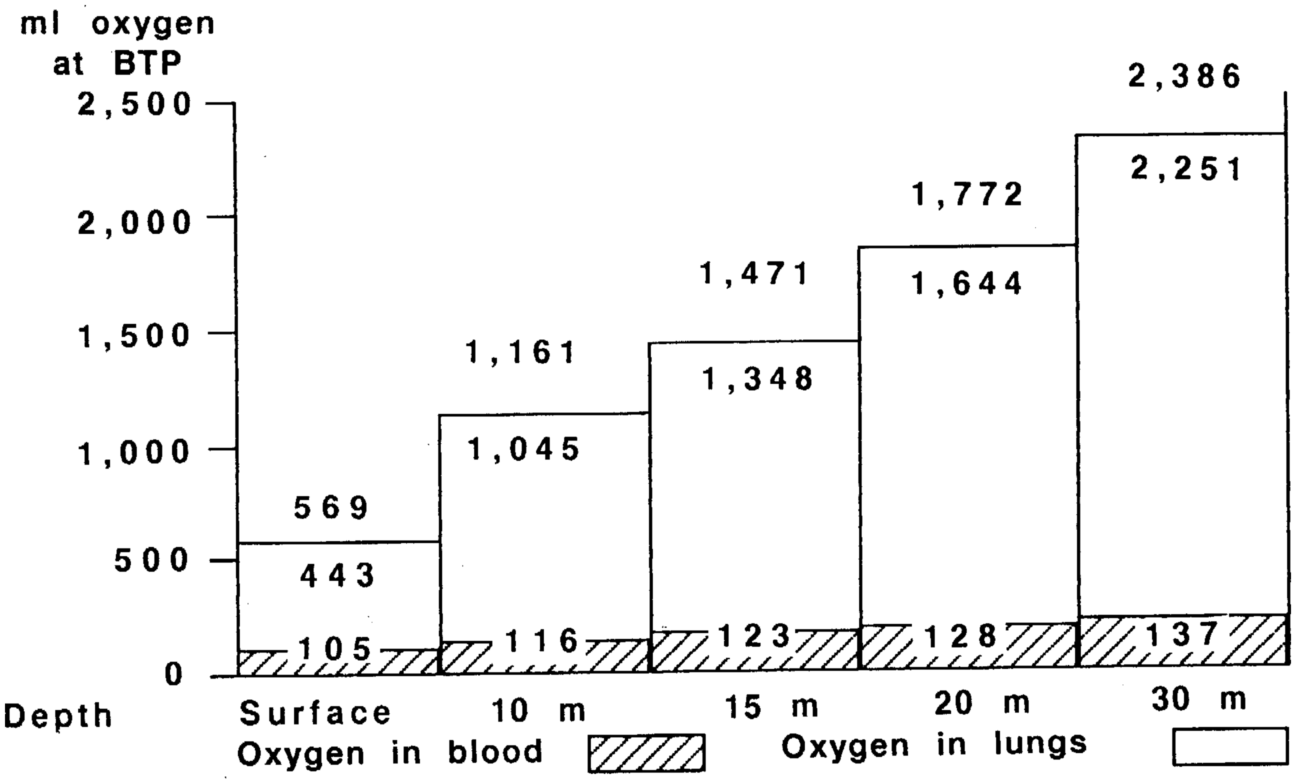
If we analyse the situation which exists when a diver runs out of air, we can derive his available oxygen (O_2), the projected O_2 cost of the ascent, and then predict the course of his PaO_2. Certain conditions must be assumed for this exercise and we have selected the following.

Our diver is an 80 kilo man, reasonably fit with a vital capacity, predicted for 184 cm height and 32 years of age, of 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 2,042 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 pro-

FIGURE 1

OXYGEN AVAILABLE AT VARIOUS DEPTHS.



Oxygen available has been calculated using a starting PaO_2 of 116 mm Hg and assuming lung volume to be FRC (2.9 litres).

duced 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).

The diver is presumed to respond to this emergency within 3 seconds by initiating an ascent and 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]

Figure 1 outlines the oxygen available on the bottom for the depth or pressures indicated.

Work by Lanphier[7] and other authors has shown that the optimum swimming rate for a diver with fins is approximately 27 m (90 ft)/minute, and that at this rate the O_2 consumption equals 1.5 litres/minute.

Using the total O_2 figures from Figure 1, less the amount lost in expired gas as the diver ascends, we can calculate the depth at which the diver's Pa O_2 will cross the critical value of 40 mm Hg which, in most of us, would result in abrupt loss of consciousness during such an ascent (Figure 2 and Table 2). 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 13.5 m (45 ft) of sea water, it takes place before the diver can hope to breathe surface air.

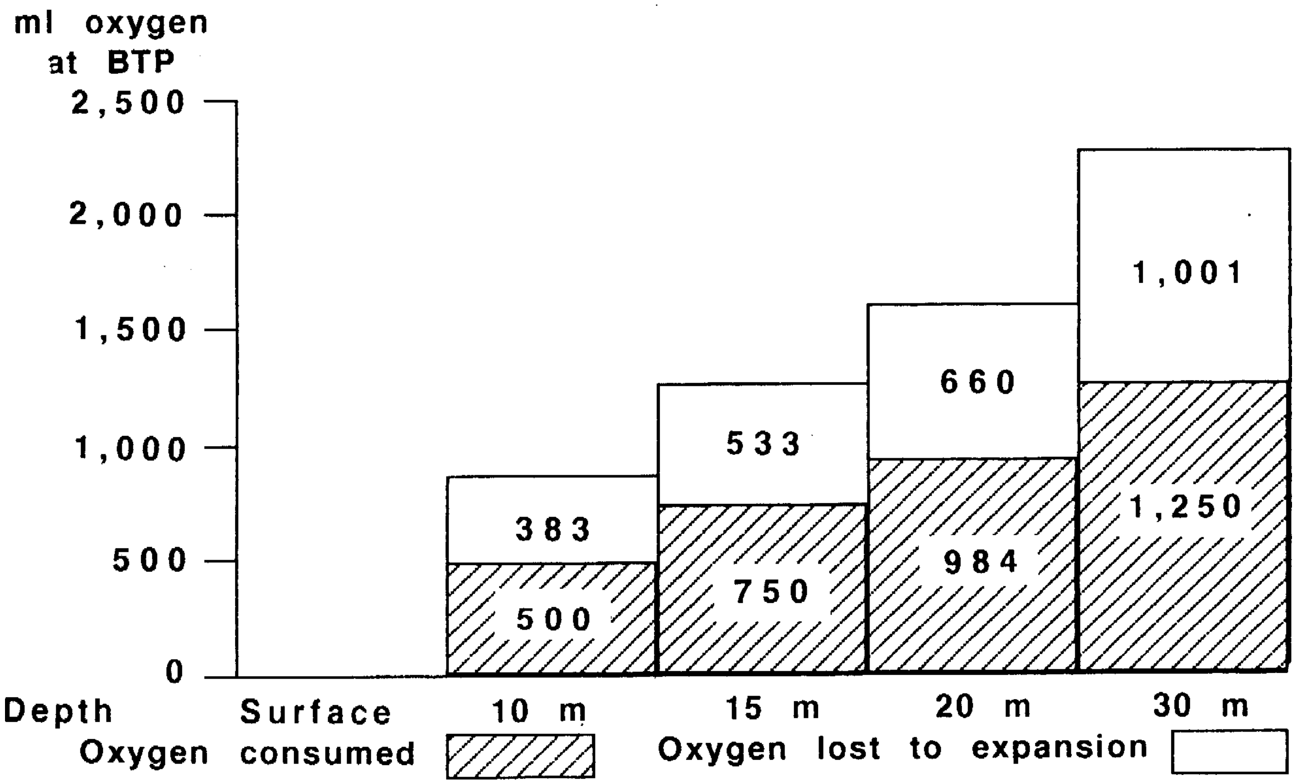
One of the conditions we assumed for this ascent at its outset was neutral buoyancy, so if the hypothetical diver loses consciousness he will not continue to ascend, rather he will lose his regulator and take in water, thereby simultaneously drowning and becoming negatively buoyant making effective rescue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

FIGURE 2

OXYGEN COST OF ASCENT



Starting depths are given in metres of sea water. The lung volume is assumed to be FRC (2.9 litres) at the start of the ascent and ascent rate 30 m (99 ft) per minute.

TABLE 2

DEPTH OF EXHAUSTION OF OXYGEN

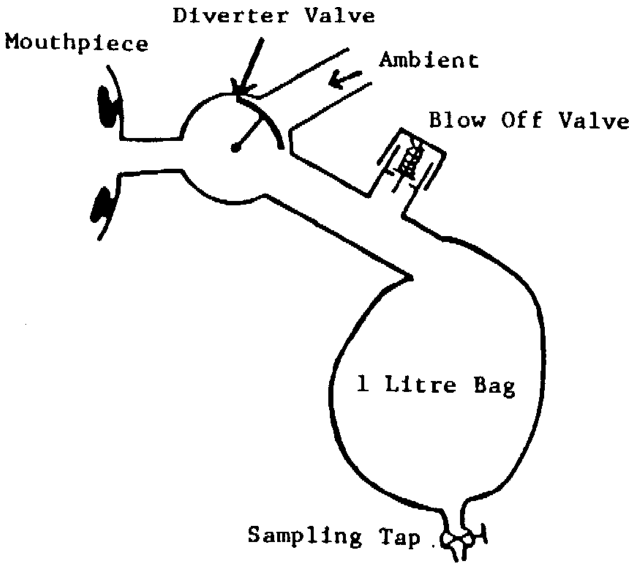
Depth of starting ascent	**0**	**10 (33)**	**15**	**(48.5)**	**20**	**(66)**	**30**	**(99)**
Depth of oxygen exhaustion	0	0	0	0	0.75	(2.5)	4.8	(16.0)
Depth PO_2 equals 40 mm Hg	0	Not applicable	1.8	(6.0)	3.3	(11.0)	8.2	(27.2)
Depth PO_2 equals 70 mm Hg	0	Not applicable	3.3	(11.0)	4.8	(16.0)	9.4	(31.0)

Depths are given in metres and in (feet) of sea water. The lung volume is assumed to be FRC (2.9 litres) at the start of the ascent and ascent rate 30 m (99 ft) per minute.

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 22m (75 ft)/min and was a comfortable one. At a prearranged signal the diver was switched to a very limited volume partial rebreathing circuit (Figure 3) and 3 seconds later the ascent commenced at as near 30 m (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 O_2 consumption equal to the cost of ascent while neutrally buoyant.[8] 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 O_2 cost. O_2 cost becomes increasingly exponential with speeds above 30 m (100 ft)/min and thus the effect would be to bring on critical hypoxia at greater depth

FIGURE 3

REBREATHING EQUIPMENT DIAGRAM



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.[9]

In addition to direct equipment and physician availability, the main lock of the chamber was held at 60 m (200 ft) throughout so that a very speedy dive to 50 m (165 ft) 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 O_2 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 O_2 by Ohio O_2 meter model No 601 with modified scale expansion and for CO_2 by modified Campbell Haldane apparatus. The results, corrected for depth and BTP, are shown in Table 3.

TABLE 3

CHAMBER TESTS AVERAGE OF THREE RUNS AT EACH DEPTH (SUBJECTS R AND H)

Starting depth	9 (30)	13.6 (45)	13.6 (45)	18 (60)	18 (60)	27 (90)	27 (90)
Subject	R and H	R	H	R	H	R	H
Depth difficulty began	Not applicable	3(10)	4.5 (15)	6 (20)	6.3 (21)	10.3 (34)	2.1 (7)
Depth terminated	0	1.2 (4)	2.1 (7)	3.6 (12)	2.4 (8)	*2.7 (9)	3 (10)
PO_2 mmHg at termination	Not applicable	48	48.4	60	55	47	56
PCO_2 mmHg at termination	Not applicable	47.7	53.5	72	81	71	58

Depths are given in metres and (feet). * denotes the subject went unconscious.

howbeit 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.

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 O_2 if necessary.

The partial rebreathing circuit was employed because of the potential for embolisation due to small airway closure if continuous exhaling routines were used. It also served to provide a source of expired gas samples, which

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 13.5 m (45 ft) 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 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 minimise 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 depths of 36 m (120 ft) are planned with a refined protocol.

References

1 *Emergency Ascent Training.* Bethesda, Maryland, UMS Report, December 1977.

2 McAniff, John J. *US Underwater Diving Fatality Statistics 1970-1979*. URI, Report No. URI-SSR-30-14.

3 Registrar General, Province of Ontario, *Statistics 1982*.

4 Kory, Dalfahan, Boren and Syner. *AM J Med* 1961; 30: 243-58.

5 Estimated distribution of blood in the vascular system of a hypothetical man, age 30, weight 63 kg, height 178cm, assumed blood volume 5.0 litres, Table IV. Barker et al. *Medical Physiology*. Philip Bard, 10th Edition, 1956, p 43.

6 Craig, A.B. Jnr, Ware, D.E. Effect of immersion in water on vital capacity and residual volume of the lungs. *J. Appl. Physiol*. 1975. 38:449-454.

7 Lanphier EH. *Oxygen Consumption in Underwater Swimming.* US Navy Experimental Diving Unit, Washington DC. 1954. Formal Report 14-54.

8 Tobermory Hyperbaric Unit. Vest trials. Unpublished data.

9 Gas tensions in alveolar air (simultaneously estimated by five different procedures) and in arterial blood (directly determined): mean values in 11 normal young men at rest at sea level. Barker et al. *Medical Physiology*. Philip Bard, 1956, 10th Edition. p 296, Table XV.

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.

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
G.D. 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; 12 (Oct-Dec): 32-39) 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.

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A LETTER FROM IRELAND

Gerry Stokes

Once again this Phoenix is raised from the ashes. I would have thought that everyone would have solved this problem in their own way by now. You posed three questions at the start of your article and the answer to them is yes it is necessary, yes it is effective, and yes it is dangerous.

You will note that all the “Rescue Apparatus” that equipment manufacturers brought out are in themselves mechanical, all of which can go wrong. A free ascent has nothing mechanical to go wrong. Yes it is necessary.

You seem to suggest that it is a common occurrence for divers to surface with completely empty tanks. This is madness!!! Where do these people learn to dive. In Ireland you are expected to surface when your air reaches reserve (50 bar) and if you have less than that questions are asked.

The only out-of-air situation we train for is mechanical failure and towards that end we recommend one of three methods. Octopus regulators including Air II, buddy breathing and free ascent, not necessarily in that order but each diver is taught all three methods and all are practised in the pool during training.

When you think about it, the first time you realise you are out of air is after exhalation when you inhale and nothing happens. Your first reaction should be to use your octopus regulator or Air II, if you have one. If not look for your buddy to share his air, but if his is too far away (i.e. it will take you as long to get to him as it would to get to the surface) then it is recommended that you drop your weight belt and swim for the surface. At least an embolism can be cured, it is difficult to cure a drowning.

You mention the debate between the medical faction and the instructor faction, well I have not heard how it goes with you, but I think there could not be much between them. The faction that differs greatly is the recreational diver faction. These people seem to want to know nothing about the problems. The proper concept of emergency ascent training should not be watered down, thinned out, or made look simple just for these people. There should be one solution for all and it should be comprehensive.

With the more common use now of octopus regulators and Air II, free ascents and buddy breathing are gradually being pushed back along the priority line but nevertheless every diver should be taught the techniques. In Irish diving we teach and practise free ascents quite successfully. To date we have not had an accident while training or practising. Initially it is taught while swimming in the pool with the regulator always in the mouth, in the sea it is practised up a shot line accompanied by an Instructor with a safety diver at the stop depth. One thing we do not recommend is changing methods on the way up. Whatever method you start with go all the way to the surface with. A number of years ago we had two accidents, not too far apart in time, where two divers buddy breathed from around 25m up to 10m-8m, in both cases the victim then did a free ascent and never reached the surface alive.

I think carrying SPARE AIR in any form is of little use, the reaction time is so short divers even forget to drop their weight belts. All the extra equipment a diver now carries is getting dangerous, too many times, all added weight and more serious bulk.

Every diver should be taught self preservation techniques, that is how he, on his own, can get from the bottom to the surface, alive. The effectiveness of emergency ascent training can be judged by the amount of time and consideration each diver gives to learning about it, which brings us back to the attitude of the instructors, and back further to the attitude of the training agencies, or dive shop or club. As was correctly mentioned in an article in the