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SCUBA TRAINING FOR THE OUT-OF-AIR SITUATION

Douglas Walker

By far the most contentious subject to raise with those who instruct scuba divers is whether practice in making an out-of-air ascent should be prohibited, permitted if performed under very strictly controlled conditions, or be made an integral part of the training course. This paper discusses dispassionately some of the background to the controversy and records the manner in which the main instructor organisations in Australia have chosen to resolve the conflict between the risk factors of the alternative possible courses of action. Tables 2 to9 are constructed from information in the Divedata Databank (Project Stickybeak) files. These files are accessible to any interested person or organisation.

Historical Background

Until pumps had been developed capable of supplying air in sufficient volume to maintain a man underwater the only way to dive was in the breath-hold mode, although some records state that Greek divers in ancient times may sometimes have used air lowered to them in cauldrons by people in boats.[1] The problem of supplying air to keep the water from rising too high with within diving bells as they descended was solved by sending air down in weighted barrels on a line, a method described by Halley[2] which remained in use till a sufficiently effective air pump was developed and users changed to this method of replenishing the bell air. He later designed a hookah system which was supplied by the pressured air within the bell. The mortality and morbidity among the workers is unknown but it is probable that accidents occurred when the workers were faced with a necessity to reach the surface or drown, with some suffering air embolism. In those rough, tough days their deaths would be accepted as due to drowning as the very existence of such a condition as air embolism had yet to be recognised.

As soon as it was realised that a man could be supplied with a continuous flow of air while wearing a helmet, which was in essence a mini-bell, the commercial possibilities were recognised. Now workers were free to move on the sea bed, no longer limited to the area immediately below the bell. The occupation of commercial diver came into existence, hardy, brave labourers who seemingly had a philosophical (or resigned) attitude to the dangers of the work they performed. The early suits were of a helmet and jerkin type, so filled with water if the wearer bent too far forwards, a design soon replaced by the standard suit (except among pearl and sponge divers). The open suits could be discarded by the wearer should necessity or panic make him desire an emergency surfacing.[3] It was such untrained divers who first made “free ascents”, luck deciding the outcome of the ascents, although the reason why the fatalities occurred was not discovered until the US Navy introduced practice out-of-air ascents for submariners and some died.

The first recorded instance of a “for real” free ascent from a submarine was that of Corporal Bauer and his two crew from 18 msw depth in 1851. William Bauer must have been an exceptional man because while trapped in the damaged “Sea-Diver” listening to anchors trying to engage themselves in the submarine’s structure, intending then to pull it to the surface but more likely to break one of its portholes, and watching water seep through the damaged joints on the hull plates, he managed to think clearly. In this he was helped by the remarkable composure of his crew. His knowledge of physics enabled him to recognise that the hatch was kept firmly closed because the water pressure was greater outside than in the submarine but that he could equalise the pressures by opening the sea-cocks to allow water to enter. That he persuaded his crew that this course of action was safe says much for his personality. All three ascended successfully despite each first taking a last deep breath before opening the hatch. The success of their response to the life or death situation was without benefit of prior training or, as far as is known, planning for such an emergency.[4]

That their survival was not a unique event can be given credence by the findings of the British Submarine Escape Mission, set up by the Admiralty to investigate known cases of escape from actually sunk submarines of all nations.[5] This noted that most of the successful escapes were made without the use of the equipment designed for use in such circumstances “but rather by free ascent or buoyant-assisted free ascent (buoyant ascent)... a result of the malfunctioning (equipment) and/or poorly-trained crews”. There is relevance in this comment to the subject of the training of scuba divers and especially to attempts to perform a buddy-breathing ascent unless both divers are well trained and have sufficient air available.

The desire to reduce the toll, and danger to morale, from both peacetime and war sinkings of submarines prompted the design of apparatus to assist the safe escape and ascent of survivors as well as attempts to develop methods of rescuing them by use of a diving bell or a submersible. It was recognised that men would be reluctant to trust themselves to the open sea at depth by exiting from the environment they knew, the submarine, unless they had some reason to trust the apparatus they were to use. For this reason a rule was made that all submariners had to pass a course involving making ascents in a test tower. The United States Navy (USN) appears to have been the first to build a Submarine Escape Test Tower (SETT), in 1930, although it is known that from the 1920s there had been testing of escape and ascent methods in the mine test tank at the Naval Gun Factory and in the open sea from diving bells and it was from these tests that the US Navy developed the Momsen "lung". It was only after the visit of Rear Admiral Ruck-Keene to the New London SETT that the Royal Navy (RN) constructed a similar tower in Gosport at HMS Dolphin.[5]

It became apparent that the SETT training was occasionally associated with fatalities despite the vigilance of the SETT instructors and for this reason a recompression chamber was first placed close to the tower and later installed at the top close to the area where those who had just ascended were watched for signs of sudden illness, now recognised as due to arterial air embolism. Indeed it was observations on such cases which led in 1931 to the realisation that such persons were not suffering from decompression sickness occurring after a remarkably short and shallow dive.[6-8] These occasional deaths also showed the need to improve equipment so that it would become more nearly natural for the person making the ascent to breath in a normal continuous rhythm.

Although it can be correctly argued that SETT situation differs significantly from that existing in the training of scuba divers because the participants start from an air environment and have no desire to be divers, rather they would never wish to enter the sea "for real" unless their submarine was trapped on the sea bed. However the close observations made of them as they ascended and the close medical backup create a source of information which cannot be matched by any diving sources. The rarity of the deaths and the fact that they still occur despite the careful management of such training makes the SETT records of interest to both sides of any discussion of the safety of practicing out-of-air ascents.

The use of a body count of fatalities is a rather crude method of determining the safety of any activity because it fails to take into account the morbidity which may be resulting in some unstated proportion of those at risk. However there are naturally many reasons why those who operate a procedure are very reluctant to investigate for possible adverse effects, particularly if there is no demand that they do so and they believe the procedure which is involved is cost effective and therefore necessary. There have however been two significant papers which indicate that there may be a hidden degree of morbidity even with carefully conducted and monitored SETT escape procedures as evidence of both cerebral air embolism and pulmonary barotrauma has been found to occur in some who have made a successful ascent and are clinically normal.[9,10]

None of this was of interest outside the small group of persons involved in the training of submarine personnel until the development of the Cousteau-Gagnan demand valve and its clones in the 1940s made it possible for recreational diving to develop, as it had early been recognised that the use of rebreathing apparatus was far too dangerous for general use. In contrast to the wartime situation, where training and operational fatalities were accepted and could be kept secret, any recreational diver who died received newspaper publicity, was the subject of coronial investigation, and had the details discussed within the then small diving community. Recreational divers very rapidly concluded that they should avoid such equipment and use only systems which supplied air on demand, the open circuit as contrasted with the rebreathing mode.

Naturally the diving community, which till then had been a small number of tough, skilled, breath-hold spearfishermen, was at once keen to learn more about using the equipment which would greatly expand their underwater time. They had no sources of instruction save those who had taught themselves (and survived to teach others), no instruction manuals, and no awareness on the part of anyone that there were any special risks, and naturally assumed breath-hold experience, usually gained in the rough water close to the rocks, prepared them to manage any situation even if their air supply apparatus failed them. Nobody then suspected the existence of conditions now detailed to every trainee diver, or rather there was no awareness of their importance. Word of this new and easier way to venture underwater soon spread, attracting a very different type of person, people who had no experience of breath-hold diving and desired formal instruction but were without diver friends who could tell them the safe way to use an "Aqualung". This was at first the generic name for all such apparatus but because this was the registered trade name of the Cousteau Gagnan apparatus there was developed the generic alternative term self contained underwater breathing apparatus or SCUBA.

Naturally this new market attracted rival manufacturers who attempted to develop apparatus which by-passed the patents of the original developers. In Australia some keen breath-hold spear fishermen with engineering skills constructed scuba apparatus for their own use, then were approached by friends to supply them also with sets and from such beginnings several small firms developed. These flourished for a time and then ceased trading when faced by the market power of large overseas manufacturers. In Australia it had been necessary for most spearfishermen to construct their own equipment so local manufacturing of this rather more complex scuba equipment was fully accepted. It is not known whether there was a similar make-your-own phase in Europe but the larger market there possibly tempted small commercial manufacturers to start up. These were able to undercut the prices of the authentic Cousteau-Gagnan apparatus and therefore enjoyed a period of success in the market. However the quality of some of these products was so poor that the users soon became aware that risk of a regulator failing was significant. In the UK this led the Kingston Branch of the BS-AC to institute the survey of some of their members in 1962 which is sometimes quoted as proving the safety of practicing out of air ascents.[11]

The survey is of particular interest because it was the only recorded such one in the UK. The original report cannot now be found but the resume shows that it was based on the replies of 36 active members of the branch. They had a total of 170 years of diving, an average of 4.73 each. The total membership of the club, adding the yearly totals for the six years 1956-1961 together, was 20,597, an average of 3433, so the sample was small and there is no information as to how representative it was of the general diving experience of the members. The report states that they had made a total of 461 practice free ascents, 25 necessary free ascents, plus 11 rapid ascents (from loss of weight belt or life jacket firing). A calculation was made to show that the club members would have made something like 30,131 rapid ascents during the six years if their diving was similar. But as a concession to any possible criticism that the sample divers were more active than the others the total was given as 15,000. It was noted that there had been no fatality in the club although SETT figures would predict such would occur, and mentioned that members only practiced a free ascent when they felt they wanted to, not in response to an order, that they did not ascend so rapidly, and were used to swimming underwater so adapted to pressure changes automatically. It is not stated whether there was any training or whether members performed a free ascent where and when and under whatever circumstances they thought fit. There is no statement that the club actually required or supervised the free ascents. This report by Hume Wallace failed to deflect Royal Navy advice that the BS-AC prohibit training involving practice of out-of-air ascents (free and buoyant ascents) "unless there was a recompression chamber ready for use at the site". Buddy-breathing training was commended, to be performed swimming horizontally with no actual ascent to be made. This was stated before the assembled BS-AC Diving Officers by Stanley Miles, David Elliott[12,13], and others on various occasions. As a concession each year 100 BS-AC divers have been allowed to attend the Royal Navy SETT establishment to be instructed in how the RN manages ascents by submariners. The reason for this offer, other than as a public relations exercise, is very difficult to identify but may indicate an understanding of the desire, which many divers appear to harbour, to practice such ascents.

As Table 1 indicates, the BS-AC has now departed from its initial acceptance of the advice it received and now includes the practicing of buddy breathing ascents in training courses. But in its defence is the fact that BS-AC courses may occupy three months rather than the five days most commercial courses take to "train" recreational scuba divers. The BS-AC courses seek to progressively increase the difficulty of the skill being taught, with monitoring of pupils to ensure that they have sufficient skills before being set more difficult tests. Whether this is understood and approved by the RN is not known, and it is debatable whether it is the time spent under supervised training rather than the actual content of the training which is to be credited as being important to diving safety of BS-AC divers. There are two additional factors which are helpful to safety, the club system and club diving officers. These may not be perfect but they have some personal knowledge of their fellow divers' abilities. This complete change in BS-AC policy has not apparently been commented upon by any RN liaison officer, which is strange. Indeed the BS-AC's Principal National Coach[14], addressing the 1987 Diving Officers Conference, stated "No one challenges the advice that assisted ascent and rescue ascent should be practiced so that divers are better trained to cope with a true emergency, and there is no question of dropping this training requirement". He added that "to get maximum benefit from the exercise it should be repeated by doing as many ascents as possible".

In other countries it continued to be accepted than all scuba pupils should demonstrate an ability to perform one or more emergency ascent in an out-of-air situation, a decision based more on doctrine than facts because there has never been any survey of European diving fatalities and in the USA the diving data appears to have been regarded as of less importance than the gut feelings of many instructors and diving medicine experts.[15] One factor which has mitigated against an impartial discussion of whether or not a practical experience of out-of-air ascents had greater benefit to the diver than the possible danger has been the semantic disputes which have surrounded and intermixed with such discussions as the original term employed, free ascent, was later used to describe a variety of methods. In this paper the term "emergency response to an out-of-air situation" has been chosen to describe what type of problem the training seeks to address.

Present Australian Training Protocols

There was a commonly agreed standard to which Australian Instructors had to bring their students so they can be given a NQAS certification in addition to that awarded on course completion by the organisation of which the instructor is a member. However the different interpretations of these course parameters has resulted in significant differences between the training programs detailed for use by instructors in different organisations and reflects in large degree the different philosophies of training which are now

TABLE 1

TRAINING PROGRAMS FOR OUT-OF-AIR SITUATIONS

Ascent	**Emergency Swimming training**	**Buddy Breathing training**	**Shared Air (Octopus)**
FAUI	No	Pool or calm sea horizontal at 2-3 m depth for 25 m then open sea at depth >5 m	Pool or calm sea horizontal at 5 m depth for 25 m then in open water
PADI (Aus)	Pool, horizontal in shallow then diagonal from deep, >30 ft exhaling continually. Ascent Open water Instructor on line Regulator in mouth from depth 20-30 ft.	Pool, stationary then swim >50 ft in shallow end. Open water get breathing rhythm then one 20-30 ft buddy breathing ascent.	Pool or calm water stationary then swim both as the donor and recipient >1 minute then donor and recipient ascents.
SSIA	20 ft ascent ** up line with instructor	Pool floor	One ascent from 20 ft depth
NAUI (Aus)	Pool, horizontal depth 2-3 metres.	Pool or calm sea 2-3 m depth then sea >5 m horizontal for 2 minutes.	Pool or calm sea 2-3 m depth then open water >5 m ascent as donor then as recipient.
NAUI (USA)	Diagonal 40 ft line in pool.	As above	As above
BSAC	No * but pool ditch, ascend, descend, don scuba, <3 m.	Graduate from land to pool to sea, increasing depth, problems sharing ascent.	as above then in sea gradually to 25 m (advanced divers), stop 6 m.
ASC (unspecified)	Requires "training in buddy system techniques" and in "out-of-air emergency alternatives"		

* See Appendix A
** This test may soon be eliminated from training

Abbreviations

PADI	Professional Association of Diving Instructors
NAUI	National Association of Underwater Instructors
FAUI	Federation of Australian Underwater Instructors
SSIA	Scuba Schools International Australia

TABLE 1 APPENDIX A

DOFF AND DON AND FREE-FLOW TRAINING

	Doff and Don	Free-flow
NAUI	Yes, in pool, keep regulator in mouth	*
PADI	*	Yes, kneeling in shallow end of pool 30 seconds.
FAUI	*	*
BSAC	Yes (voluntary), in pool, <3m, ditch, surface, descend and don. Also ditch as fast as possible.	Yes, during mask clearing and buddy breathing lessons, kneeling in pool in shallow water
SSIA	*	*

dominant in the USA and the UK. In essence the dispute is between whether in the limited time available for basic training there is to be stress on avoiding problems or on escaping the consequences of mistakes or misadventures.

There are only two basic reasons for a diver to be in a situation where he or she is unable to ascend using the original air supply: the equipment may be entangled but the wearer can ditch it and get free, or the air supply has become inadequate or failed, as occurs when the scuba tank is functionally empty or there is some malfunction of the equipment. Considered thus, the submariner has to abandon the submarine trapped on the sea bed but is unlike the diver in that he now has a secondary air supply, an escape suit, to enable a breathing ascent to be made after discarding the primary equipment (the submarine). Similarly, hose-supply divers should be wearing a bail-out bottle to avoid the consequences of out-of-air situations due to equipment failures. The out of air or low air(no/low) status scuba diver has by definition no reserves of air, this being the essence of the problem. Though not all hose-supply divers wear a bail-out bottle the majority appear to quickly learn to survive occasional compressor failure situations by making an emergency ascent as soon as their air supply ceases. They learn by having to face for-real out-of-air situations. Fatalities usually, but not invariably, being in the inexperienced users of such apparatus.

The situation is therefore that a scuba diver will only need to exercise an ability to make an emergency ascent if either the equipment becomes irretrievably entangled, fails suddenly or he or she runs out of air. The latter is by far the commonest and should be totally avoidable by following the accepted safe diving rules. That so many diving-related fatalities are associated with divers who are in a low or out-of-air situation is a matter which deserves urgent attention (Table 2). Possibly there is inadequate stress during training on adopting a “defensive diving” attitude, the recognition of and response to potentially adverse situations before the crisis stage, and too much time is spent on showing how to respond after an out-of-air crisis has occurred. There is only a limited time available for instructing pupils so course content is necessarily a matter of compromises. These are much influenced by the prejudices of those involved and their attitudes to the competing philosophies for survival in an adverse environment. One can learn to identify problem-breeding situations and act in a manner which avoids their development to a critical degree, or accept that such critical situations are unavoidable and concentrate training time on the management options of such crises. In an ideal world there would be time to address both options, the prophylaxis and therapy approaches to diving safety.

It is possible that the initial source of the belief in Australia that practicing of some form of out-of-air ascent ought to be part of scuba diver training was the UK, an importation of the initial BS-AC training which was not modified after the RN advice to omit such training practices was reluctantly accepted by that organisation. In recent years the influence of US beliefs has been a significant factor due to the dominant position of the Professional Association of Diving Instructors (PADI) and the National Association of Underwater Instructors (NAUI) in scuba diver training in Australia, with the Federation of Australian Underwater Instructors (FAUI) alone continuing with its acceptance of the advice from both RN and Royal Australian Navy (RAN) to avoid practicing emergency type ascents. Despite the significant differences which exist over this matter between each of the training organisations (Table 1) they have agreed to recognise each other’s certificates of scuba training,

TABLE 2

SCUBA DIVING FATALITIES 1980-1988

	Total	adequate air	no/low air	No Air	Low Air	N/s
Australia	62	18	39	23	16	5
New Zealand	56	17	28	20	8	11

TABLE 3

SCUBA DIVER FATALITIES 1980-1988

CAGE V LOW/NO AIR STATE

	Number	Adequate	No or low	Not Stated
Australia				
Total	8	-	7	1
Had gauge	7	-	6	1
New Zealand				
Total	12	3	6	3
Had gauge	11	3	5	3

TABLE 4

SCUBA DIVER FATALITIES 1980-1988

TRAINING STATUS V NO/LOW AIR STATUS

	Number	No training	In class or some training	Trained sometime, somewhere	Not Stated
Australia					
Total	62	13	9	38	2
No/low	39	7	6	25	1
New Zealand					
Total	56	15	4	21	16
No/low	28	8	2	10	8

though obviously there will be some instructors who will regard divers trained by another organisation as having received a less good training than that necessary for safety.

There are two factors to consider when seeking to reach a decision as to whether any of these differing teaching programs can be considered the one of choice. The scuba divers produced by the course should have a safety record at least as good as divers taking alternative courses, and those elements in the course which differ from alternative course schedules and have a potential for causing morbidity should be clearly demonstrated to produce safer divers better fitted to recognise, and manage, all probable diving-related adverse situations. All courses should produce divers who are aware of the limitation of their skills, that they are novices on completion of any course until experience has resulted in them reaching the stage where the new knowledge has been so integrated into their cerebral databank that it is now part of the automatic response pattern in any diving-related emergency situation.

This requires that the training exercises have not only been practiced sufficiently to make their repetition accurate and automatic, sometimes called "over-learning", but also be safe enough to be repeated by divers to maintain and improve the skills after leaving the instructor-controlled situation of a class. Naturally the relevance of taught skills can only be established through an examination of the apparent critical factors revealed by analysis of actual diving-related incidents, and as changes occur in diving practices and equipment there will be changes noticed in the kind of problems which most significantly effect divers. Training will need to take account of such changes by adding to or amending the content of courses.

The out-of-air situation in scuba diving fatalities

An examination of the adverse factors found on analysis of scuba diving fatalities indicates that a low-air or out-of-air situation has been present at the critical time in far too high a proportion of the incidents to be other than a significant factor which has influenced the course and utcome. It disadvantages the victim, reducing his or her options in devising a successful response to whatever was the immediate problem. In only one instance did a catastrophic failure of a scuba air supply system occur and there were additional adverse factors involved here, for this victim was totally untrained and using scuba for the very first time. In one other case a low air situation was tragically terminated when the diver's buoyancy vest's venting valve failed during ascent and as an additional complication one weight had moved, jamming the quick release of the weight belt. The discussion of factors relevant to diver safety is limited in this paper to avoidance of the low air and out-of-air situations and assessment of probable outcome, risk versus benefits, for different teaching protocols which presumably instil in trainees different patterns of response should they be faced with such a situation. As it is inevitable that no training course in recreational scuba diving can afford to allocate enough time to produce divers who are more than novices on completion of their training, all courses must be a compromise and true learning comes from the repetition of what they have performed only a very limited number of times during training.

Possibly the first significant finding is that while a no/low air status was present in the majority of cases of cerebral arterial gas embolism (CAGE) such cases form a relatively small proportion of the instances where air shortage had occurred. This is shown by comparing tables 2, and 3. The tables are all based on the case reports in the Project Stickybeak Divedata Databank, with the diagnostic label of CAGE being applied where a description of the incident made this the probable critical factor. In addition, in most instances, the autopsy findings were confirmatory. One can therefore deduce that a no/low air situation is not inevitably an event which is followed by a CAGE. In the majority of instances a combination of additional factors influence the course of events, and although the cases considered here ended fatally it is likely that the majority of low air situations were successfully managed by those involved. Diver safety will naturally be enhanced by the strict avoidance of a low air status although an understanding of the correct response to such a situation is undoubtedly of value. Logic suggests that the low-air state should be less serious than to be without an adequate air supply as in the latter situation a necessity to reach an air source will severely limit the response options, an assumption supported by the data (Table 2) which shows that out-of-air fatalities outnumber those with low-air status.

The next important finding (see Tables 4 and 5) is that the no/low air situation occurs with significant frequency across the full spectrum of training and experience. This can be taken as an indication that neither initial training nor diving experience is teaching scuba divers the need to monitor their remaining air and to ascend while still having sufficient air to meet any emergency situation. It is also apparent (Table 6) that such situations are developing proportionally more frequently in those furnished with a contents gauge than those without such an aid. As the gauges in these cases are not faulty the problem must lie with the users, an indictment of their diving techniques. The majority of no/low air situations, on such figures, appear to be avoidable.

The importance of the buddy diving principle is the one matter taught in all courses of instruction, although it is common to observe that many divers follow this precept somewhat loosely after release from the class situation. There has probably never been a formal investigation concerning the correctness of this advice to divers. However it is noticeable that solo or separated divers are far too frequently the victims of fatal incidents to support a change in opinion concerning the apparent adverse effect on diver

TABLE 5

SCUBA DIVER FATALITIES 1980-1988

STATED EXPERIENCE V NO/LOW AIR STATE

	Number	No or slight experience	"Some" experience	Experienced	Very experienced	Not stated
Australia						
Total	62	23	16	19	4	-
No/low	39	10	15	11	3	-
New Zealand						
Total	56	15	17	14	3	7
No/low	28	8	9	7	-	4

TABLE 6

SCUBA DIVING FATALITIES 1980-1988

CONTENTS GAUGE AND NO/LOW AIR STATE

	Number	No Gauge		Gauge		Not Stated	
		Total	no/low air	Total	no/low air	Total	no/low air
Australia	62	14	8	48	31	-	-
New Zealand	56	6	3	36	21	14	4

TABLE 7

SCUBA DIVER FATALITIES 1980-1988

DIVE GROUP AND NO/LOW AIR STATUS

	Total	Solo	Diving with buddy			Diving in group		
			no	separation		no	separation	
			sepn	before	during	sepn	before	during
Australia								
Total	62	6	10	20	11	4	11	-
No/low	39	4	8	13	7	1	6	-
New Zealand								
Total	56	15	3	27	7	-	4	-
No/low	28	7	1	14	2	-	4	-

safety related to a solo situation (Table 7). It cannot be claimed as statistically certain because the proportion of divers at risk who are similarly solo or separated is unknown. One thing however can be stated, they are as frequently in a no/low air situation as are the generality of scuba diver fatalities and certainly cannot seek emergency air from a buddy.

The role of the buoyancy vest may be debated, whether it is for surface support, to permit buoyancy control at depth, or for its lift capacity when the wearer wishes to ascend but has excess weight. It is now common for the buoyancy vest to be of the backpack type which uses the scuba tank as its air source. One result of this is that when the wearer is in a no/low air situation this has the effect of making the inflation system inoperative because in an emergency situation no diver will have the breath to orally inflate the vest. The congruence of no/low air and the wearing of a tank supplied buoyancy vest is shown in Table 8.

It has been shown that the majority of fatalities occur at the surface or at relatively shallow depths and this holds for the no/low air fatalities also (Table 9). If the case reports are examined it will be seen that inexperience, water conditions, being solo or separated, retention of the weight belt, failure to inflate the buoyancy vest, and medical conditions (most commonly these are cardiac) are frequently significant additional adverse factors. A singularity in the data from New Zealand is the comparatively few surface fatalities where the air supply was deficient. The reason for this has not been determined.

Discussion

There are a number of aspects of this problem which may be considered as requiring consideration:

1. Is the no/low air situation adverse?

The response options of a scuba diver to adverse events will inevitably be reduced should there be a need to conserve air because the remaining supply is running low, and become even fewer as the supply fails. Study of case histories indicates that there are usually several adverse factors present in incidents in which the dead diver was later found to have a low-air problem and they all influence the course of events. Naturally training and diving experience are assets but they do not guarantee survival where an out-of-air or low air state occurs (Table 4, 5). It has been shown that although cerebral arterial gas embolism victims are commonly found to have been out of air, the majority of fatalities where an out-of-air state has been present do not suffer this ending, which may plausibly be taken to indicate that it is the presence of one or more such additional adverse factors which convert a situation from a potential to an acute crisis for the diver. By implication the air status is not the single critical factor, though one which may play a crucial part in the progress of events.

There are several ways in which the no/low air state in a dive may be a danger. It will cause a degree of anxiety, have an influence on decision making, affect the inflation of the buoyancy vest where this is supplied from the scuba tank, make exiting more dangerous and a surface swim back to the dive platform mandatory. There will be the additional factors that no precautionary “deco” (decompression), or more properly, “safety” stop will be possible and a severely reduced ability to provide a buddy with air. Without an air supply a diver cannot submerge and continue to breathe, an action which may be life saving in rough sea conditions. Panic is more likely to occur if the diver is without an adequate supply of air.

2. Is the no/low air situation avoidable?

There is only one responsible reason for running out of air while scuba diving and that is where there has been some kind of sudden equipment failure. Such events appear to be rare, though a free-flowing regulator or freeze-up could prove equally serious to an unprepared diver. In all other diving situations the divers should monitor their air, and if necessary their buddy’s, to ensure that surfacing and return to the dive platform is commenced while adequate air still remains. As shown (Table 6) it is not only the divers who are without a contents gauge who become low on air. In fact those who have a contents gauge appear to be proportionately more represented in the no/low air category.

Although there have been some minor inaccuracies in the contents gauges in some instances, none of these was a sole reason for a fatality. There appears to have been no pressing reason for victims to have failed to heed their gauges. Had they done so the probability is that they would not have died.

3. What is the best response option?

Naturally the best response is to become aware that the air supply is becoming low and commence ascending immediately. If correct dive procedures have been followed the buddy is close by, but if the buddy is some distance away it will be a waste of very valuable air to swim horizontally to the buddy rather than making a solo ascent. Case reports suggest that a buddy-breathing ascent in such circumstances is liable to fail disastrously, either when the donor also runs out of air or the rhythm of exchanging of the regulator is not honoured. Unless the buddy pair have established, through practice with each other, a mastery of the buddy breathing technique they will find it difficult to perform in the emergency they now face. If they have been so safety motivated to have made the effort to train with each other they are unlikely to have got into such a low air predicament. The use of the buddy’s “octopus” regulator eliminates the dangerous consequences of any failure to exchange the regulator equitably. However there still remains the probability that the buddy’s remaining air is becoming low and if subjected to a doubling of demand will run out rapidly, which will necessitate both divers having to perform a “free ascent” for the final portion of their ascent,

TABLE 8

SCUBA DIVER FATALITIES 1980-1988

BUOYANCY VEST TYPE AND NO/LOW AIR STATUS

	Number	No vest	Vest inflation method				Not stated
			oral	CO2	LP hose	Fenzy type	
Australia							
Total	62	13	-	7	36	3	3
No/low	39	5	-	3	27	2	2
New Zealand							
Total	56	15	6	3	18	-	14
No/low	28	6	3	1	11	-	7

TABLE 9

SCUBA DIVER FATALITIES 1980-1988

INCIDENT DEPTH V NO/LOW AIR STATUS

				Depths in metres					
	Number	**Surface**	**Ascent**	< 10	10-20	20-30	30-60	>60	**Not stated**
Australia									
Total	63	22	6	9	5	1	6	2	12
No/low	38	12	4	6	4	-	3	2	7
New Zealand									
Total	56	17	7	6	5	3	2	-	16
No/low	28	4	5	5	2	3	-	-	9

risking air embolism.

There are some diving situations where direct ascent is not possible, as in cave diving, and here it may be necessary for a diver to buddy breathe for a horizontal distance but for this type of diving special training is mandatory and management of the air supply is one of the most stressed safety factors.

It is not possible to discuss instances where there has been a successful ascent using buddy breathing or shared air (the use of an Octopus regulator) because reports of such are lacking, a regrettable consequence of poor information gathering. However it is likely that such ascents became necessary due to one of the divers failing to monitor his or her contents gauge, which should not occur and is a self induced situation.

It has been suggested that no/low air situations can be expected to become rare with the increasing habit of scuba divers to have an octopus rig, two cylinders with independent regulators, or to carry a small emergency (pony) cylinder. Human nature being what it is, the most likely outcome will be that the diver will, in most instances, treat the additional cylinder air as available for the dive rather than an emergency reserve. There would still be a need for the diver to respond correctly to the warning of the low air status which was developing. In the early days of scuba reliance was placed on the diver recognising the onset of some difficulty in obtaining the air. The first attempt to solve this problem was by developing the J valve to create an air reserve. Later the sonic warning systems were introduced. None proved reliable. It could be held that a diver who fails to take cognisance of the information which his contents gauge provides has failed to learn correctly and that greater time should have been spent on this during the training course.

It may be claimed, though without documentation, that the training courses which include ascents after simulated out-of-air situations have saved lives and that such divers are not shown in fatality records. Against this is the fact that for many years in the UK the BS-AC has prohibited the inclusion of any actual ascent training in the out-of-air procedures and there is no evidence of this having been an established adverse factor in such fatalities as have involved their members. The primary reason for setting up the Project Stickybeak Divedata Databank was to establish a basic data resource to enable an examination and evaluation of the many factors which influence the evolution of any "incident". For this reason it has always been recognised that reports about non-fatal incidents would be highly valuable. Unfortunately, and world wide, the diving community has failed to recognise the vital importance of such reports. The reasons presented for this reporting failure are several but generally based on the claim that confidentiality promises could be dishonoured and the reports used as a basis for legal actions. Such fears are rarely justified and the risks have been minimised by designing the scheme so that the control of all reports is medical. It is often forgotten that the basic facts of incidents are not so much unknown as undocumented so there is not really any protection from non-reporting if some aggrieved person is desirous of instituting an action for damages. However failure to report makes it harder to identify problems and their possible remedies before a serious misadventure occurs.

In the de facto no/low-air situation the diver involved is likely to unexpectedly receive an inadequate supply of air and need to respond urgently. It is here that training and experience provide protection against panic, and BS-AC experience supports the premise that such training need not include practice of emergency procedure ascents. It has not been shown by follow-up assessments that the few practice ascents which are made during training courses have inculcated an ability to perform shared air ascents in those so trained which is panic-proof in a crisis situation.

The ability to make a successful ascent after becoming aware of being in a no/low air is probably a function of having confidence that it is possible and an understanding of the manner in which it should be performed. Training which extends to reach the stage of over-learning is not practical when courses must be designed with tight cost and duration constraints. So recreational divers are likely to find their emergency-ascent skills will very rapidly degrade after they graduate, but in an emergency situation they can probably ascend safely and without apparent morbidity despite the less than perfect performance of ascent procedures. This would be a reflection of the body's "redundancy principle" which ensures a continuation of functions despite trauma unless the damage occurs in a vital position which is not protected by a back-up. There are many instances of untrained divers making successful ascents, particularly those using unreliable hose supply equipment.

4. Does emergency ascent practice train or only demonstrate?

Numerous repetitions of a new skill are necessary if it is to become integrated so that it can be performed without any conscious thought in response to the relevant stimulus. There can be no such over-learning of emergency ascents because even the proponents of this procedure admit that there is a minimal risk associated with it (but balance this against their claim that the benefits outweigh the risks). In order to maintain and even improve their skills some divers will practice what they have been taught in the class situation but without an instructor in attendance to ensure an accurate performance. This unavoidably introduces a potential long term risk element into the history of such divers and also may reinforce the attitude, which they may have, that entering a no/low air situation is safe as they know how to reach the surface. However the records indicate that the surface itself gives no guarantee of safety when some additional adverse factors are present. The no/low air state has a danger potential which is additional to the obvious ones of either drowning or suffering an air embolism in seeking to reach the surface and air, so avoidance of such a situation has potential benefits in comparison with the attempt to become skilled in performing emergency ascents.

Some speakers at the UMS Workshop[15] recorded the opinions of their organisations on the question of how many repetitions of a new skill were necessary before the pupil was likely to perform it in an emergency situation. Smith (YMCA) suggested 17 exposures to buddy breathing were necessary, Egstrom (UCLA) quoted the views of diving officers from various institutions that a diver was not trained until he had performed 8-12 successful open water dives, a standard not achieved by their courses, while Miller reported that NOAA divers had to make 15 open water dives before attaining the category of "limited diver" and 100 before "unlimited diver". The view of Dr Lanphier was that he "did not feel very confident that ascent training in the open water adds a great deal to what could be accomplished with optimal classroom and pool training, although there are no numbers available on the subject", that such training should be a thoroughly voluntary procedure on the part of pupils, not required for certification of any group.

The BS-AC courses extend for far longer than those which are run by the commercial organisations and continue beyond basic training to include the "optional but recommended" section called Confidence Building Exercises. In a pool the equipment is removed and the pupil exhales while ascending, takes a breath, descends, and dons the equipment. There is a second exercise where equipment is ditched as rapidly as possible, remembering to disconnect a direct feed hose from the buoyancy vest. Table 10 shows the requirements for such exercises among the various diver training organisations.

5. What are the risks?

There have been no known fatalities in either Australia or New Zealand associated with the present training methods but a reference to the SETT experience shows that "hits" can occur even where stringent supervision is maintained. It has also been shown that subclinical pulmonary barotrauma and cerebral air embolism occur in the SETT situation. It is likely that similar events are happening in those practicing shared air ascents. These ascents suffer from the serious disadvantage, inseparable from their basic design, that a minor mistake in performance may be followed by the rapid and possibly irreversible occurrence of morbidity. Although probably the majority of diving-related fatalities are identified and their critical factors analysed in Australia and New Zealand, such is far from being the case in other areas of the world where investigations may be less complete and documentation less easily accessible. By chance there has been one instance in Australia in recent times where two divers were apparently practicing a buddy-breathing ascent, though not under supervision, and one died during the ascent. Both were experienced and were on an Advanced Divers' course at the time. Hardy (NAUI) reported to the UMS Workshop[15] the fact that in the period 1970-76 the 5 major training agencies in the U.S.A had lost a total of 80 people during training, 20 during ascent training. DAN data has note of 11 instances where diving instructors had suffered injury after running out of air and/or when making rapid, panic ascents.[16]

One aspect of the ascent procedures taught is that pupils have to exhale in a forcible and continuous manner and this introduces the possibility of creating some areas of air trapping due to the collapse of some small air passages. It is far more physiological to make some inhalation efforts during ascent, even if there is no air available, as this will tend to open up any collapsed passages and allow the distal alveoli to vent. By keeping the regulator in the diver's mouth there is also a chance that there will be air available as depth lessens and ambient pressure falls so that the pressure of the air remaining in the tank again becomes sufficient to activate the regulator.[17]

Although the ascent methods as taught may not appear to cause any fatalities directly they may be inculcating in divers a dangerous attitude to air conservation, an unstated belief than to continue diving until almost all the air has been consumed is the clever way to dive as one is not paying for more air than is used on the dive. While it might be counterproductive to teach a pupil to regard running out of air as being an irredeemable error there should be greater stress on informing pupils that scuba diving is safe only as long as the diver remains capable of making suitable adjustments to the environment. This includes having a sufficient supply of air to inflate the buoyancy vest, perform decompression, being able to accept being washed back off rocks by water power when attempting to exit, and having the option of swimming underwater when surface conditions are rough.

Because there is no certain information concerning what proportion of scuba divers habitually, frequently, or occasionally, use most of their air supply before commencing their ascent, there can be no firm conclusions drawn from the data in Table 1. But in considering the matter it should be remembered that their chances of survival would almost certainly have been considerably greater if they had to contend with even one fewer problem. There is need for a survey of scuba divers to ascertain their response patterns to air monitoring, and a confidential survey of scuba divers about occasions when they recognised a serious adverse problem might be overtaking them would be of enormous value because their survival would provide information not only concerning the problem but the successful response they employed or others provided.

Summary

The problem facing Instructor organisations in devising training protocols was accurately defined by Dr Nemiroff in 1977, at the UMS Workshop:[15]

"One of the difficulties is that we are trying to train a skill for an emergency context that requires either a high degree of skill, or extensive reinforcement, or over-learning, or all three. In a true emergency, where the mind is not working and the body is not functioning the way it should, the emergency technique that would be best would be one requiring absolutely zero skill, a zero memory, and zero reinforcement. Therefore I have no answer to what the best emergency technique is, but it seems to me that we should strive for those that require minimum skill, minimum reinforcement and yet can be considered valid exercises under the conditions."

Although not so identified by Nemiroff, such a "zero skill" exists and is the option which every diver has to avoid continuing until he or she enters the no/low air state.

Readers should consider their response to the following questions which bear on the options open to those who train scuba divers. It is recognised that instructors are required to conform to the training program set forth by the organisation which gives them authority to graduate their pupils. However no rules need be regarded as beyond critical examination and the following list of heads of discussion may serve to stimulate such an examination.

1 Is the no/low air situation to be regarded as adverse?

2 Is it avoidable by taking simple prudent care?

3 Is knowledge of emergency ascent procedures sufficient or is actual practice necessary (consider case reports)?

4 Does the usual course practice teach or only demonstrate emergency ascent methods (is over-learning achieved)?

5 Is the possible danger of air embolism during training outweighed by the benefits (note SETT experi-

ence and the absence of proof that such training has been beneficial to scuba divers who follow advised rules for safe diving)?

6 Course time is limited. Is time better spent in thorough indoctrination in safe diving practice or in practicing emergency ascents, i.e. accepting that no/low air situations are inevitable?[18]

7 Are pupils warned of the potential dangers in practicing such ascents when unsupervised by a trained instructor and of the likely decay of their skills if they are not practiced?

8 Are pupils to be advised that their buddy is likely to have a reduced air supply when theirs is no/low status and that a tank supplied buoyancy vest fails to operate when the tank is near empty?

9 Is there any evidence that there is justification for the differences in the scuba training courses defined by each major Instructor organisation?

This paper does not provide a definitive answer to such questions because there is inadequate data available (i.e. incident reports) to form a firm basis for a definitive analysis. There is a need for instructor organisations to recognise the value of the Divedata Databank concept of confidential management of reporting of all types and severities of diving-related misadventures and to take a more active stance in supporting efforts to obtain such reports.

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SCUBA DIVING AND PREGNANCY

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Introduction

Diving during pregnancy is a relatively new concept and consideration in obstetrics. Over recent years with the influx of improved equipment and the accessibility to the equipment necessary for diving, the number of divers has greatly increased. The percentage of women divers has also dramatically increased. As few women consistently dived in the 1960s not much thought was given to the effects upon them and their unborn child whilst diving. As the number of women divers increased during the late 1970s and on into the 1980s, this is increasingly becoming an area of concern for many women. 20% of the diving population are women and they are mostly of the child bearing age.