tection. *Anesthesiology* 1984; 54: 34-42.
7 Cooper JB, Newbower RS, Long CD and McPeek B. Preventable anaesthesia mishaps: a study of human factors. *Anesthesiology* 1978; 49: 399-406.
8 Mackie I. Alcohol and aquatic disasters. *Med J Aust* 1978; 1: 652-653.
9 NSW Department of Leisure, Sport and Recreation. *Drink and drown: the fourth water safety symposium* Sydney: Department of Leisure, Sport and Recreation, 1980.
10 Plueckhahn V. Alcohol and accidental drowning. A 25 year study. *Med J Aust* 1984; 2: 22-25.
11 Knight J. SPUMS members and the tables. *SPUMS J* 1988; 18(3): 115-116.
12 Wilks J and O'Hagan V. Queensland scuba divers and their tables. *SPUMS J* 1991; 21(1): 11-14.
13 Edmonds C and Walker D. Scuba diving fatalities in Australia and New Zealand Part 3 The equipment factor. *SPUMS J* 1991; 21(1): 2-4.

Acknowledgements

I wish to thank Dr R Webb for his valuable computing skills and help with the Diving Incident Report Form; also Professor W Runciman, Drs D Gorman and Williamson for their support and encouragement and Mrs E Brown for her secretarial support.

Dr C.J.Acott, FANZCA, Dip DHM, is the Co-ordinator of the Diving Incidents Monitoring Study (DIMS).

He has been Secretary and President of SPUMS.

He is a Staff Anaesthetist at the Royal Adelaide Hospital. His address is the Hyperbaric Medicine Unit, Department of Anaesthesia and Intensive Care, Royal Adelaide Hospital, North Terrace, Adelaide, South Australia 5000.

SPUMS ANNUAL SCIENTIFIC MEETING 1991

EMERGENCY AIR SHARING

Glen Egstrom

Introduction

The purpose of this paper is to focus upon a positive approach to the standardisation of an important emergency procedure, sharing air. The behavioural aspect of this procedure could be effectively standardised with a minimum modification of equipment and existing techniques.

Why share air ?

Other than in training classes, one is normally only going to have to share air when one's buddy is out-of-air. It is a time of considerable stress. An out-of-air situation is most unlikely for a scuba diver who monitors his or her air supply. It can happen, but it is rare.

In many parts of the world regulators freeze. When gas expands it tends to cool. Air is expanding when it comes through the low pressure hose. We have tested a series of regulators at various temperatures and at various depths. Virtually all the regulators on the market will freeze up if they get cold enough and have enough air going through the regulator. Typically the regulator valve will stay in the open position, a free flow, and with free flow you get a tremendous cooling effect causing ice to form on the outside and on the inside of the regulator. Sometimes the regulator will freeze shut. This is a difficult and serious problem. In between sheet ice actually forms on the diaphragm increasing the breathing resistance. The increase in breathing resistance is enough to create additional stress as the diver may feel that he is out-of-air. Every regulator available is going to be more difficult to breathe from at low tank pressure and at depth.

A tropical diving holiday is probably the worst possible environment for a scuba diver. It takes about 72 hours to get about 80% acclimatised. Divers rarely have that long before they go to work enjoying themselves. Inspite of understanding the problem, we consistently let ourselves become dehydrated during the first two or three days. We are not sensitive to the need to push fluids when we arrive in the tropics. In addition we are offered deep, clear, warm water, party times and late nights. We are not as well prepared for some of our dives as we should be. As a result mistakes are made.

Many people who encounter increased breathing resistance interpret that as an out-of-air situation. It is important that people recognise that if one breathes slower and so keeps the peak flow rates low, then the resistance is going to be lower and one will be able to get air out of the tank comfortably for much longer. In most of the regulators on the market excessive breathing resistance starts about 500 or 600 psi tank pressure at depths of 20 m or more. Most of the good regulators on the market have different characteristics because the balanced first stages are so finely tuned that they will work up to a critical pressure and then fail to deliver. The diver has no warning, one breath has some change in breathing resistance and then one does not get the next breath, or if one does, one only gets part of it.

Out-of-air is a time for an emergency ascent. If one starts air sharing one should begin an emergency ascent. Emergency air sharing should not be done while one finishes the rest of the planned dive. That does happen. I know a diver who chooses young women as diving buddies because they do not use much air. When he gets tank his down to about 300 psi, he shares her tank until it is nearly empty. Then he uses his remaining 300 psi to surface.

The past

I have participated in recreational scuba and scientific diver training and in commercial and military diving. Those involved in training divers are obligated to have people less confused at the end of instruction than when they started.

There are problems with emergency air sharing. I hope to give you a better understanding of how the present situation developed and to persuade you to convince your communities to try to simplify emergency air sharing.

The Undersea Medical Society, now the Undersea and Hyperbaric Medical Society, convened an Emergency Ascent Training workshop in December 1977. Thirty-five experts representing training organizations in all facets of diving spent two full days discussing the topic. Position papers and statements were compiled in a publication and made available to the diving public. Reactions to the positions were also recorded and published. There was a strong emphasis on unaided ascent as well as on air-sharing ascents.

During the years since the conference there has been little, if any, progress towards standardisation of the latter emergency procedure. Recommendations have come from many sources and small groups within the diving field have instituted programs for their own divers.

Emergency procedures should meet certain criteria if they are going to be effective for large populations. The procedure needs to be

1 Standardised.
2 Easy to learn and reinforce.
3 Logical and require a minimum level of skill.
4 Reliable and effective.

Swimming ascents

Twenty years ago an emergency ascent was all very simple. One did a swimming ascent. One took ones regulator out of ones mouth, tipped ones head back, blew bubbles and swam to the surface.

The military called this a "free ascent", a term which recreational divers immediately picked up. Some of the training agencies, like the Los Angeles Underwater Instruction Agency, insisted that divers had to be able to do a free ascent from whatever depth they dived to. That was considered ones safety valve. If a diver was going to dive to 30 m, the diver had to demonstrate that one could, on a single breath, get all the way to the surface, exhaling all the way. We all managed to do it and no one gave it much further thought. As time went by, the US diving medical community told the training agencies that free ascent was a dangerous practice which should not be done, either in training or in any other circumstances.

Buddy breathing

The way round this prohibition was "buddy breathing", again a military practice. Diving was supposed to done in buddy pairs. It was the responsibility of each member of the buddy pair to be there to help if needed. The procedure for sharing air was very simple. One swam up to ones buddy and drew a hand sharply across the throat, giving the signal that one wanted to share air. The buddy would immediately take the two hose regulator out of his mouth, roll it over and put it into position so that the recipient could get a couple of breaths. Then the donor would roll it back and so on. At the same time as buddy breathing commenced, the divers would hold each other, so they were securely linked together. This particular technique works very well, if one has been trained to execute it. But buddy breathing was the thing that one did only if one could not make a safe swimming ascent to the surface.

With single hose regulators, one took the mouthpiece from ones mouth, passed it immediately to the side and then back and forth. After some accidents we realised we had to teach people that they had to exhale during the time they were not breathing from the regulator. The concept was that one had to see bubbles at all times except when inhaling from the regulator. Had we been really on the ball at that time, we probably would have have suggested that the airless buddy could put his or her mouth over one exhaust valve outlet, block off the other and breathe the expired air. Two people can breathe off a single regulator with very little difficulty if they practice the skill.

Sharing air did lead to some horror stories such as, "I gave my buddy the regulator and he would not give it back". The failures of the buddy breathing system led to remarks about how dangerous it was and that one would have to fight for ones life if one gave ones regulator to someone. Every time I read, in a accident report, that the buddy system failed, I get livid. The buddy system does not fail, it is the people using it that have the problems. The system is fine, it is the implementation that falls down. Usually that is because of lack of practice.

Secondary regulators

The octopus (spare regulator) concept was a logical step. Theoretically if one has an extra second stage all a recipient has do is swim up and put it in their mouth. Unfortunately when the octopus was accepted a major error of judgement was made as we violated a basic precept in emergency procedures. We failed to standardise the location of the spare second stage and failed to standardise the procedure of air sharing.

Shortly after the octopus came in I asked a diving group the question "What would you do if you run out-of-air and you wanted to share my air?" The whole group put an open hand in front of my face. I did not understand what they meant. They explained that they were going to grab the regulator out of my mouth and I would give it to them because that signal meant "I want to take a breath". Unfortunately only they knew what that signal meant. If they dived with others they would not be able to communicate.

Even if one communicates the basic issue of "I'm out-of-air. I want to share" there are two scenarios.

In the first one, the person with air takes his primary life support means and puts it in the buddy's mouth and then has to find his spare second stage. I like to keep my primary regulator and give my buddy my alternative air source. I know the primary works, but I am not certain about the octopus. It takes very little particulate material to create problems with the mechanism of a 2nd stage. The octopus should be in a convenient place where the buddy will get a clean regulator and where both divers can find it. Is it necessary to give up the primary air source? Do I have to give up the one in my mouth that I know is working? I do not have a problem and I do not want one. We may have a problem, but it is really my buddy's problem. I will help in any way I can but if we are going to have an emergency, I want to keep it simple.

In the second scenario the out-of-air buddy takes the spare second stage. Unfortunately it is unlikely that the buddy knows where it is going to be because most divers permit their octopus to hang loose. Mostly the regulator hangs somewhere, even down between people's legs if it is on an extra long hose, dragging in the sand. Some divers even position the octopus so that that one cannot tell whether they have a one or not.

My point is that there is still no standardised procedure for octopus breathing. There is a standardised procedure for buddy breathing, although in some programs buddy breathing is no longer taught, neither is the swimming ascent.

Whether we use buddy breathing, octopus breathing, breathing from an alternate air source or from a pony bottle one has to have a procedure, standardisation of the action and common agreement on how this is going to work.

Some of the manufacturers' innovations are located in a standardised position. The Air II, a breathing device, is always on the end of the inflation hose and incorporates the ability to automatically inflate the buoyancy compensator while still being able to be used as an alternate air source. This eliminates one low pressure hose.

However the Air II requires that both buddies know how it works, which buttons do what. The manufacturer's instructions say that when someone comes up and indicates "I'm out-of-air and I want to share" one gives them ones primary device. But this advice is not because the primary regulator is in a standard position where the buddy can get it. It is because they hope you know how Air II works and accept that your buddy may not.

At UCLA we completed some experimental behavourial studies. We found that one can leave the primary in ones mouth and hand ones buddy the Air II. Certainly it is on a short hose, all that does is bring the buddy in a little closer. One does have to turn it to the outside which results in the hose kinking. However it is very, very difficult to prevent any air coming out of a low pressure hose, with about 140 lbs of pressure in it, by kinking it. There is always sufficient pressure to activate the Air II. However it was shown to be important that the air source be in a fixed position in order to avoid delays in the smooth pass to the recipient's mouth. Velcro or other attachments need to be substantial enough to hold the second stage in a stable position but must allow easy disengagement.

Diving is now a technologically driven sport, driven by incredibly rapidly expanding technology. We used to think it was an instruction driven sport. Perhaps in the early days it may have been, but no longer.

Instead one or two new products per year, we see a multitude of new products, innovations on existing products, and a burgeoning diversity of equipment, resulting in a diversity of methods of handling functions. Other manufacturers have the copied Air II. They are all basically a breathing device that is incorporated into the automatic inflation system. There are probably a dozen variations, all with different kinds of controls, all requiring specific training in order to make the device work.

One needs to have a standardised procedure for using a second regulator and both parties must understand the rules. To make sure both buddies understand the procedure one should try it out on the surface before the dive. During an actual emergency is not the ideal time to try to learn how unfamiliar equipment works.

Pony bottles

Pony bottles have the advantage of being a completely separate air supply. They have the disadvantages of not having a standardised location for the spare second stage and of being a another thing to take on every dive because one does not know when an emergency is going to occur. The one thing about emergencies is that they occur with sobering suddenness according to Murphy's Law.

An enterprising gentleman in California, recognised that people did not like the idea of the large pony bottle, but did want an independent secondary air supply. He came out with Spare Air, a small cylinder of compressed gas, with a regulator on top and a way of monitoring of how much gas is in it. One turns it on before a dive. If one works in a heavy current, it may be activated and bleed off. But if one waits until the emergency to turn it on, the person wanting air may get a little tense during the operation. The manufacturer suggests keeping it in a holster. The diver comes up, gives the signal and one whips it out and hands it over and they are ready to head for the surface.

Spare Air does not require that you break the primary life support link. It has the advantage that you can fill it from a scuba cylinder. The manufacturer found an incredible market, not only divers but also helicopter crews who have actually bought more than divers. When a helicopter goes into the water, it usually inverts and everyone is confused and it sometimes take several minutes to get out. If one can not breathe, escape gets to be dicy. With Spare Air they have several minutes to find a way of getting out and be saved.

Spare Air has a drawback. The early ones simply did not give enough air at depth. At 50 m, one got one full breath and a part of another. At about 18 to 24 m one would get anywhere from 4 to 7 breaths and on the surface 14 to 16 breaths or so. They have now come out with a 3,000 psi cylinder. It is available as a set of doubles.

The problem is that the devices will work well, but in order for them to work every time the spare air source has to have a standardised location, standardised procedure and users with a common set of rules to be able to utilise it in a safe and effective manner.

The ideal is that if you are outfitted with a primary, an octopus, a pony bottle, a Spare Air or a Air II, in a standard location, then when the buddy comes up, they can say "I think I'll have one of these" and life will go on.

Standardisation

One of the big criticisms of the number of devices is it is always possible that the recipient may not know how to use the secondary air source and therefore grabs the primary regulator. The donor then has to sort out the problem, otherwise the other diver is likely to panic. From a human factors point of view it does not make any difference what system one uses. The basic steps one has to go through are the same. There has to be some linkage of the divers and there has to be a transfer of an air source.

If the devices were located in the triangle between the edges of the rib cage and the mouth, this would make it easy to find them. In our tests placement of the air source anywhere in that triangle resulted in an easy pass, as long as the hoses, if any, passed over the shoulder or were attached near the shoulder in a fashion to permit the air source mouthpiece to be placed in the recipient's mouth.

In this discussion you will note that the recommended procedures would not require the donor to remove the primary regulator from the mouth except in the case of buddy breathing. Mounting the alternate air source within the triangle formed by the mouth and the outside lower borders of the rib cage has several advantages:

1 The air source has a consistent, semi-permanent location.
2 The air source is visible to recipients as they approach.
3 A single movement with the right hand can quickly move the air source to the recipient's mouth.
4 A single basic behaviour pattern is possible for the recipient and donor.

One must do the simple things, standardise the location of the alternate air source and standardise the procedure so that whatever signals are given are standard, and the response is to get an air supply from what the diver happens to be carrying. Buddy breathing even works with this system, for people who still utilize this practice. The procedure has to be kept simple. If it is complicated the amount of training needed to overlearn the skill increases dramatically. To learn to use an octopus properly takes over 12 tries to get it right, and this is with a standardised location. Buddy breathing takes from 17 to 21 tries.

Regardless of which system one uses, if both people are not prepared by training, having overlearned the skill to the point where they do not have to think about it during an emergency, it is going to be difficult to perform. If you go into a problem solving mode at the same time as you are involved in an emergency, it is quite likely that you will screw up whatever you decide to do. Any emergency skill must be learned so that it is essentially reflex. The diver can then deal with some other issue and still be able to go through the mechanics of air sharing without thinking about it, whatever else is going on. One of the things that needs to be done in training programs is that when novices have learnt the mechanics of air sharing, they then need to do some rehearsals under additional stress. They need to be able to solve other problems at the same time they are air sharing. One of these problems is propulsion. What tends to happen is while buddies solve the air sharing problem they usually stop swimming. They need to be trained to do two or three things at the same time as they are air sharing. It is amazing how few people can do this.

If one has stress involved in whatever emergency procedure one is going to use, or anticipates that one is going to use, one uses more air. That is the nature of stress. The solution is stress avoidance and reduction. To reduce stress, there are various things we can do. One is mental rehearsal. I once did a research project that showed that one can get reinforcement of individual skills, learning and maintaining those skills if one does mental rehearsal exercises. One imagines going through the process of whatever is going to take place. The difficulty in the case of sharing air, is that both people have to rehearse the same technique under the same mental set of conditions. Talking is a most important way of reducing stress and one that is very rarely used properly. One asks ones buddy "How are we going to handle an out-of-air situation?" and the buddy says "By buddy breathing". Yet you really have not communicated how you are going to do the action. One can bet that what happens is not what you expected, unless you both trained in the same program, on the same system and with the same set of conditions.

There are other problems coming. The recreational diving community is getting interested in the technological aspects of diving. When asked about mixed gas diving, nitrox diving or deep diving, base your advice on what recreation is all about. If they are insistent that they wish to do such diving, then they need training by some competent organization that specializes in that particular sort of diving. This is because how they they do their emergency procedures will vary according to the equipment that they are going to wear. If they do not train in that equipment for particular kinds of emergencies that are likely occur, it is unlikely that those emergencies are going to be successfully handled.

Conclusions

Without getting involved in the controversy over which of the techniques for air sharing is the best, an examination of the problems reveals a procedure which would meet the above criteria with a minimum of retraining or expense. Both the donor's response to the out-of-air signal and the recipient's actions shourl be standardised.

If the diver does not take independent action in the form of a controlled emergency swimming ascent we have an individual who goes to a potential donor for air. The "out-of-air" signal (hand drawn sharply across the throat) followed by the "I want to buddy breathe" signal (hand and fingers motioning toward the mouth) could be given during the initial contact regardless of the manner in which the air supply exchange would proceed. A person who wants air would therefore always follow the same procedure.

1 Signal out-of-air.
2 Signal for sharing air.
3 Establish contact with the donor.
4 Guide the offered air source to the mouth without taking it from the control of the donor.

The donor should respond by
1 Grasping the other diver's harness or tank and facing the recipient.
2 Immediately pass an air source across to the mouth of the recipient who will now be facing the donor.

So far the procedure is well established in the field and should present no new problems. The donor may be prepared to share air by
1 Using buddy breathing.
2 Using an alternate second stage.
3 Using a device such as the Air II.
4 Using a redundant system such as a pony bottle.
5 Using some other suitable device.

Unfortunately there are a number of variations within each of these procedures which complicate the problem of standardisation. However the donor holding part of the recipient's gear while passing an air source can be standardised. These moves can be done quite easily if the air source is in a consistent location where the donor can, in a single move, grasp the air source and pass it to the recipient's mouth. The recommended location is on the front of the chest in the triangle between the edges of the rib cage and the mouth.

The principle issue is that when the individual who wants to share air comes to the donor, the same procedure is always followed. This behaviour then triggers a response from the donor that is functionally the same with regard to the mechanics of the movement irrespective of other factors, such as the type of device being used to share air.

The establishment of a standardised procedure does not mean that dive buddies should feel that there is no need to discuss or even rehearse the procedure prior to the dive. Training is paramount in any emergency procedure.

There is a learning curve associated with the skill of air sharing. In the case of buddy breathing, a study conducted by the the UCLA Diving Safety Research Project determined that 17-21 successful attempts were needed for performance without errors in a group of basic students. Retesting, after three months of diving without reinforcing the skill, showed degraded performances, involving errors in procedures. Not only should the skills be well learned, but they should be periodically reinforced, especially in circumstances where the buddies are diving together for the first time. Use of alternate air source breathing such as alternate second stage, Air II, pony bottle, etc., also involves the learning of a series of skills. These procedures are as complex as buddy breathing up to the point of sharing. The basic difference is that the recipient receiving an alternate air source need not alternate breathing with the donor. This is a substantial advantage in many cases. It is folly, however, to assume that these alternatives to buddy breathing do not require substantial learning and reinforcement.

It is possible to conceive of "what ifs" that could create additional variables and interfere with a smooth procedure. Adequate training, education and dive planning will still be required in order to minimize the "what ifs" and their effects.

This is an edited text derived from a lecture with slides and from the text of a previous publication provided by Dr Egstrom

Glen H. Egstrom, Ph.D., is Emeritus Professor of Kineseology, at the University of California, Los Angeles (UCLA). His address is 3440 Centinela Avenue, Los Angeles, California 90066, U.S.A.

RESPIRATORY FUNCTION IN INTENDING DIVERS

Andy Veale

Introduction

The history of diving medicine has moved through a number of different phases. Firstly, divers simply went diving to accomplish a particular aim, there was no consideration at all about the physical or physiological attributes necessary to perform this work safely. Occasional deaths and illnesses then occurred, and attempts were made to explain these deaths using physiological and pathological knowledge obtained in other situations and in other disorders. Rules have then been derived from these extrapolations. Of necessity these rules or standards, are conservative due to the lack of basic knowledge, the desire to be exhaustive and to avoid any perceived medico-legal risks. Finally, the "natural" data accumulates and research data is collected, suggesting that theoretical concerns have been overstated and standards are ultimately relaxed. One very good example of this is the relaxation of standards for aircrew following spontaneous pneumothorax in all Air Forces.

I believe diving medicine needs to become more scientifically rational in terms of risk assessment in order to be perceived by the diving community as acting in the interests of divers, to avoid the "them and us" situation.

Lung anatomy and physiology

I shall briefly cover some aspects of the normal lung anatomy and physiology before pointing out some of the changes in normal physiology which occur during diving. I will then discuss some of the possible mechanisms of barotrauma and how these have been used to justify some of the theoretical risks, and hence contraindications, in current diving standards. I will then discuss the actual risk data, and the potential pitfalls in interpretation of this data, before proceeding to a brief philosophical discussion of what the doctor's role should be.

The lung is a very elastic structure which tends to collapse towards functional residual capacity (FRC). FRC represents a balance between the tendency of the lung to collapse and the tendency of the chest wall to spring out. Most of the lung elasticity is in the bronchovascular bundles which contain most of the elastic and non-elastic connective tissue. The bronchi and vessels tend to run together within bronchovascular bundles and during inspiration or overinflation there tends to be a tractional force along these bronchovascular bundles. Within the walls of the bronchi smooth muscle is oriented in a circular or spiral fashion, becoming increasingly discontinuous toward the terminal bronchioles, leading to areas of potential weakness.

During a normal forced expiratory curve flow rate rapidly reaches a maximum and then falls as the airways become narrower, acting as a flow limiting step. Flow at low lung volumes is thought to reflect flow within the small airways but even in these terminal portions of expiration, flow is still significant at around 800 ml per second.

The compliance of the chest wall and lungs varies considerably with the phases of respiration. Starting from expiration increases in lung volume cause little change in intrathoracic pressure. However at the extreme of inspiration a very small increase in volume is associated with a marked increase in intrathoracic pressure. So any reduction in depth (pressure) while a diver is at total lung capacity (TLC) will very rapidly increase the intrathoracic pressures and as a result the tractional forces along the bronchovascular bundle.

During head out immersion there are significant changes in pulmonary physiology. The lung becomes much less compliant due to the central redistribution of blood volume, closing volume is increased and specific airways resistance and the work of breathing are increased dramatically.

Increasing gas density leads to progressive, and quite marked, declines in flow at all lung volumes.