A NEW APPROACH TO OUT-OF-AIR ASCENTS

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The various instructor organizations in the world have been plagued for some time now with the problem of what to teach about emergency situations and how to teach it without incurring excessive risk to students and liability to themselves. Already rates for instructor insurance are climbing as the courts demonstrate willingness to increase the scope and degree of liability by their awards. This situation has lead to serious recommendations at national meetings of instructors organizations that nothing be taught to novice divers about emergency ascent, that it should be reserved for advanced classes. Such actions would be tantamount to suggesting that only pilots who survive the first year should be taught how to do emergency landings.

In considering the matter of emergency ascent we must of course recognize that once panic occurs our ability to influence the out-come ceases. The remainder of this submission is directed at the diver who is still in control in an effort to examine his options and hopefully to develop a logical course of action which if followed, will both prevent panic and ensure the safest possible ascent.

It is perhaps relevant to point out at this juncture that teaching a technique doesn't necessarily involve practicing it. The FAA suspended the practice of force landings because such practices too often turned into the real thing. In the same vein it should perhaps be pointed out here, that the inappropriate nature of the initial response to emergencies is what converts many mishaps to disasters. Professional instructor organizations have prepared various statements on ascent training culminating in the NSTC ascent agreement.

In this agreement which is quoted in the abstracts, the first two options to be presented to students are:

1. The use of octopus regulator;

2. Buddy breathing

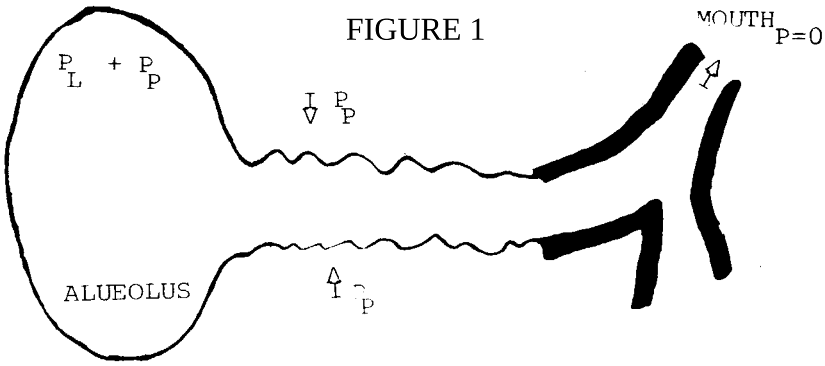
Both of these alternatives are taught in Canada as elsewhere, despite the fact that in our very cold waters doubling the mass flow through the first stage significantly increases the chances of freeze up which will deprive both rescuer and victim of air. Buddy breathing is also fraught with difficulty in waters which leave one's lips too numb to feel. Perhaps more significant are the omissions. No-where does this document mention the importance of psychological preparation. It fails to suggest immediate movement upward if difficulty is even suspected; worse it suggests evaluation before taking any action. Would it not be better to take conservative immediate action while evaluating, eg. signal to buddy and commence a normal ascent at once?

What remains to be determined now is the safest way of executing an emergency ascent, if this becomes necessary. A great deal of information exists about various methods of rapid ascent (buoyancy assisted) and as this represents the most extreme case any technique which is successful in this instance must embody principles important in all ascents. First, it has been apparent that a closed glottis is a potential hazard from earliest times. Passively holding the glottis open is a difficult feat; reflexes tend to close it at all times when respiratory activity doesn't require it to be open.

Recently in Toronto Sick Children's Hospital, while conducting a study using physiologist physicians as subjects, Dr AC Bryan found only four of nine could perform this act. To avoid this problem Stenke advocated having the subjects head covered by a hood containing air and teaching them to keep breathing. The success of this technique shows the validity of his concept. Still there are failures. Some of these failures have been attributed by Boenke and others to small airway closure and subsequent air trapping. Techniques have been suggested to avoid this but to date no detailed explanation has been published relating the pulmonary dynamics during the ascent, to the potential hazards. We know from work by a large group of researchers including Macklem et al. and Fry et al. that we all produce closure of some small airways with each expiration, the precise percentage varies from 10% for healthy 18 year olds to 40% in 65 year olds. In water in a vertical position due to the pressure gradient applied to the chest wall, there is an increase in this trapping at the bases as shown by Dahlback and Lundren. If we examine now a sequence of alternatives for a hypothetical lung perhaps the difficulties will be more readily appreciated. As our principle concern is with sports divers a suitable depth from which to start their hypothetical ascents would be 50 feet with the diver starting at or near FRC as the diver most frequently becomes aware of his plight when he attempts to breathe in after normal expiration.

At this point (see Figure 1) the state of affairs in the lung can be represented as shown. The precise ration of patent to closed alveoli would vary with the lung zone. In the normal person above water, the collapsed segment reopens with the next deep breath or sigh. The diver cannot do this if he is out of air, but he has several options open to him. First, he may elect to blow down to RV and then hold his breath to the surface, or "blow and go". As the glottis is closed during this manoeuvre, if the ratio of RV to TLV for the subject exceeds the ratio of pressures passed through during ascent, a burst lung will result. A young healthy diver will permit a ratio of RV/TLV of 1/3.5 and so will escape this problem in our hypothetical case. Older divers will not be as fortunate as their ratios may be exceeded depending on their respiratory status.

FIGURE 1



P_p = Pleural Pressure - Large
P_L = Elastic recoil of Lung - Small
As flow begins, resistance to flow causes pressure drop. Then eventually this drop = P_L.

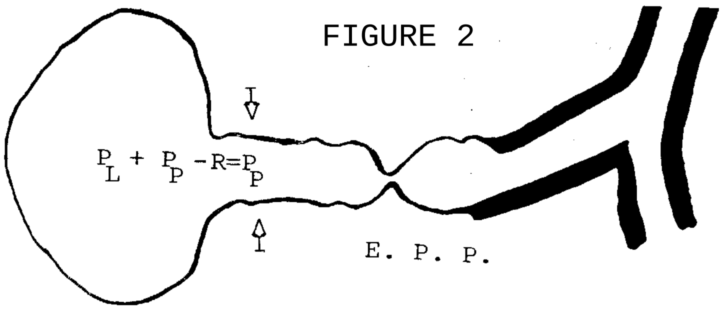
For the fortunate diver who escapes this consequence of Boyle's Law let us examine the sequence of events in the lung as he rises towards the surface. The intrapleural pressure starts off negative. As the lung expands, it becomes less negative due to the attempt to rebound to FRV (FRV in water is lower than FRC in air), but as the gas in the lungs expands it too becomes positive. The forces which produced the airway closure are no longer operative. The lack of interdependent forces has been restored by parenchymal expansion. The dynamic flow situation leading to the locating of the, Equal Pressure Point of Mead, Macklem and others within the collapsible segment of the air-way is no longer present, as the glottis is closed and flow has ceased. In addition expanding alveolar gas leads to increasing alveolar pressure which assists in air-way opening in conclusion then this would seem a reasonable approach for young divers with no anatomic anomalies or scars which might lead to the trapping of excess gas provided they can be certain they are in 60 feet or less of water.

The next alternative is the most widely taught response. The diver rises to the surface blowing out as he goes. If we examine this situation a potential hazard becomes apparent. If one of the alveolar units closed during the expiration contains more than 1/3 of its potential volume and if the diver maintains expiration to the surface, from 50 feet it may rupture. Note that the first alveolar units to close, are those with the lowest elastance or highest compliances. The continuance of these expirations maintains the dynamic flow force which produced the closure, surface tension forces assist in this regard and interdependence forces are prevented from becoming significant by the lack of lung expansion. Any interruption in this expiration, especially any attempt at inhalation, can rapidly alter this sequence of events. A fact which I feel has saved many divers. Whether the pressure required to burst an alveolus in this situation is lower than that required to open the closed airway has not been proven but the possibility exists and would explain most of the unmerited burst lungs we see.

The next alternative to be explored is the possibility that the diver could ascend attempting inspiration all the way. In this situation the pleural pressure remains negative at all times. The interdependency forces grow as the lung expands assisting in opening closed airways. The glottis is open and the airways maximally patent so out flow resistance is minimal and the gas free to behave in accordance with the dictates of Boyle’s Law unless the ascent rate exceeds the maximum rate seen with the Stenke hood, which is improbable, the way flow rate generated by the effects of Boyle’s Law would be of the order of 3-4 litres per second which is well within the limits of rates measured in exercising. This then might be the best of the alternatives for very rapid ascents but needs further investigation and because the procedure is psychologically difficult it may never be the best for sports diver.

Sports divers rates of ascent even when buoyant would rarely approach 200 feet minimum unless using unisuits, but the benefits of the continuous inspiration may be achieved in most cases by simply maintaining a cycle respiration. This will ensure the glottis is kept open and that pressures are cyclically altered so that in the inspiratory phase, opening of small airways is encouraged. The students should be taught to emphasize deep inspirations and to increase the rate of respiration with the rate of ascent.

FIGURE 2



Once closure occurs - How does it reopen? - Surface tension holds it closed if lung volume decreases. Little elastic recoil and P_L very small.

At the rate of ascent encountered in submarine escape, a normal rate of respiration could easily lead to the subject being in expiratory phase all the way from 60 feet to the surface and thus resulting in a burst alveolar unit. This could perhaps be avoided by either continuous inhalation or rapid panting at relatively higher lung volumes during ascent.

As an instructional unit our next concern here was with methods of instruction. To reduce the psychological shock caused by out of air situations, we teach all our students to expect to run out of air on every dive. We teach them to do the usual safety check, and to use underwater gauges and octopus regulator. We also teach them not argue with their gear, under water. Regardless of what the underwater gauge says, if you are having difficulty getting air comfortably, signal your partner and start up gently. If the problem is progressive, the time saved by the immediate start up may prevent panic and save life.

To train actual emergency ascent we proceed as follows. In the pool, we have students swim up along the bottom slope breathing in and out, we increase the speed and emphasize the need to breathe in and out. Next in 10 feet of water we shut off the students tank with a hand on the valve, watch to ensure they encounter the difficulty (ie. breathe out and fail to get air), then swim with them as rapidly as possible up the slope watching to ensure that they seem to attempt to maintain a cycle of respiration. This procedure is discussed and repeated as often as needed to get the student comfortable. We repeatedly emphasize that you maintain breathing in and out or attempting to do so against dry regulator or closed lips, and that you increase the rate of this cycle if you are ascending more rapidly. Finally we repeat the drills in open water using repeated swimming and buoyant ascents with air on to depth of 25 feet and air off ascents gradually increasing from 10 to 30 feet on a tethered line, one on one, instructors hand on the air valve.

For special candidates who dive with unisuits (eg. Canadian Government Arctic divers), we also do progressively staged blow ups from depths to 30 feet using high lung volume panting routines. One difficulty we encountered in this group of divers was unique to the air filled suits. A somewhat stocky diver who fitted his suit rather well, especially at the wrist and neck seals, got into severe difficulty at the surface because of the high pressure retained in his suit. It took fast action on the part of his tender to rescue him from this dilemma.

For these concepts to be accepted as valid, certain questions remain to be answered. Can it take more pressure to open a collapsed small airway than that required to rupture the alveolar wall? Answers to this are hard to determine. Studies of the pressures required to open small airways have all been done on intact lungs which, because of the interaction of hydraulic and mechanical forces may behave quite differently from the isolated alveolar unit which may have only hydraulic forces acting on them. Typical figures cited for such intact lung studies give pressures of 4.5 cms H_20 (Burger and Macklem) to re expand collapsed airways. If we look at a single collapsed airway of radius “r”, the pressure required to open it is presently not known. We are attempting to find a modification of the La Place law that might cover this situation as a starting point. The burst pressure of an unsupported alveolus is similarly unknown as indeed is the burst pressure for a terminal respiratory unit divested of support from surrounding units. While these and many other questions are being explored and hopefully answered several important changes can be made in current practices without hazard.

1. Instructor organizations can standardize 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 of alveolar rupture due to trapping

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