There is an important practical implication of these findings. It means that if you go diving when you have, or have recently had, a cold, influenza or an attack of bronchitis, which has left you with some viscid mucus in your chest, then you are in danger of getting an unexpected attack of severe Type II decompression sickness. All the men I have known who have suffered from an unexpected attack of Type II decompression sickness have been found on enquiry to have had a cold in the week or ten days prior to the dive and had presumably returned to diving before their lung mucus had had time to return to normal.

* * * * * * * *

Brief Profile

Prof. Dennis Walder is the leading expert in Britain on bends and compressed air problems. He is Chairman of the Society for Underwater Technology diving technology committee, President of the Undersea Medical Society and of the European Undersea Bio-Medical Society and Chairman of the Medical Research Council Decompression Sickness Panel. He is based on the Department of Surgery, University of Newcastle upon Tyne.

* * * * * * * *

NINETY SECOND DEEP SCUBA RESCUE

GD Harpur, MD

(NAUI News January 1974)

It is proposed in this study to review the problems posed by the unconscious diver and to present solutions available to the diver attempting rescue.

The unconscious diver has ceased to breathe. There may be several reasons - depletion of supply, contaminated supply, equipment malfunction, the little appreciated danger of cold, or other medical problems. He will have lost his regulator, and his oxygen stores rapidly deplete. Unless he, or a rescuer is able to replenish these, he will die.

Illustration No. 1 shows a comparison of oxygen consumption with elapsed time in a non-breathing subject whose heart is still beating. Depending on the reason for his loss of consciousness he is left with a certain amount of time until he will have sustained irreversible damage to his brain and only a little longer before he will die. At the point in time when his arterial pO_2 drops below the level of 40 mmHg, (normal level = 80-90), his consciousness will be very much impaired. The time remaining after this until his pO_2 arterial drops to levels which will result in a permanent alteration in the diver's central nervous system is approximately 90 seconds. This does not mean that anyone found on the bottom known to have been down in excess of this time should be abandoned or handled differently, but attempts to point out that we should aim at developing a rescue technique which will take less than 90 seconds.

ILLUSTRATION NO. 1 (page 18A)

What is needed to treat an unconscious diver, assuming intact circulation, is a source of oxygen and ventilation to remove CO_2. Is this possible deeply underwater? It may be. A standard two stage regulator with purge button cannot be utilized as a ventilator on the surface as the exhaust ports free flow, any attempt to obstruct them can lead to application of full intermediate pressure to the lungs or instant embolus. In water it is possible to ventilate with a regulator because of the substantial pressure gradient which exists for very small differences of depth (eg. 44 lbs. per sq. inch per foot or in centimetres of water 1 cm of water pressure per 1 cm depth). By inverting the victim it is possible to have a pressure on the exhalation ports of the regulator 30mm. In excess of the pressure on the lower chest wall (in this case since the diver is inverted it would be his upper chest wall). The regulator must be inserted with the victim upright and purged before inverting the unconscious diver for as the victim is turned to the inverted position the reversal of the pressure gradient to which the chest is exposed will result in an effective inspiration. The victim would inhale water, then, if the regulator is not in place (see Illustration No. 2). In most situations this technique is of no particular value and because it is difficult to perform alone valuable time may be wasted. If the diver begins to recover underwater serious problems are bound to ensue with panic no matter how experienced the person is. The technique may be useful, however, in situations such as saturation diving, cave diving, or wreck diving where either a habitat is close to hand or escape to the surface would result in severe decompression illness. If the surface is not accessible this technique might be useful.

It is worth emphasizing at this point that the unconscious diver's air supply must be suspect. If his tank is not empty, why is he in difficulty? Regulator malfunction or contaminated air supply may be possible to rule out. If the safety of his supply is uncertain then the rescuer's supply would be the only source available and the procedure becomes increasingly unwieldy unless an octopus regulator is being used. Mouth-to-nose resuscitation can be and has been carried out successfully by my associates and me but requires an extremely relaxed operator with previous practice. The hazard of recovery and ensuing panic is ever present. The exact technique for performing both mouth-to-nose and the previously mentioned artificial ventilation with regulators of all types will be described in detail in a separate paper to follow. There remains but one obvious source of air for an unconscious sport's diver - the surface air.

Hazards exist on the surface too. Boyle's Law has to be considered. Boyle's law will have its greatest effect between 30 feet and the surface when the air in the lungs will expand to twice its original volume. If a person leaves 30 feet with 4.0 litres of air in his lungs he will have 8.0 litres of air in his lungs on reaching the surface if none escapes.

If he has only 6.0 litres of a total lung volume he will have ruptured his lungs and probably have sustained an air embolus.

In an unconscious diver the following can obstruct the air passage.

1. Flexion of the neck. While true for inspiration or driving air into the lungs, it is not valid for exhalation because the pressure of air from below can passively open the passage. This is similar to a cork in a bottle which can be pushed out from below and rapidly becomes loose yet wedges tightly if pushed down (see Illustration No. 3). A simple experiment can prove this - draw in the biggest possible breath and have someone push the chin down on the chest

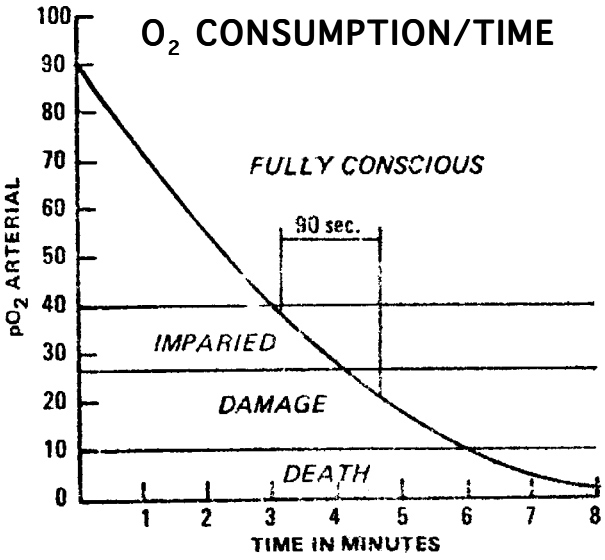


ILLUSTRATION NO. 1

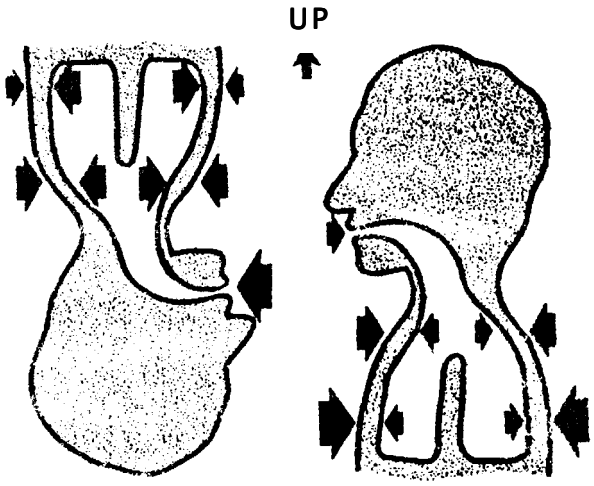
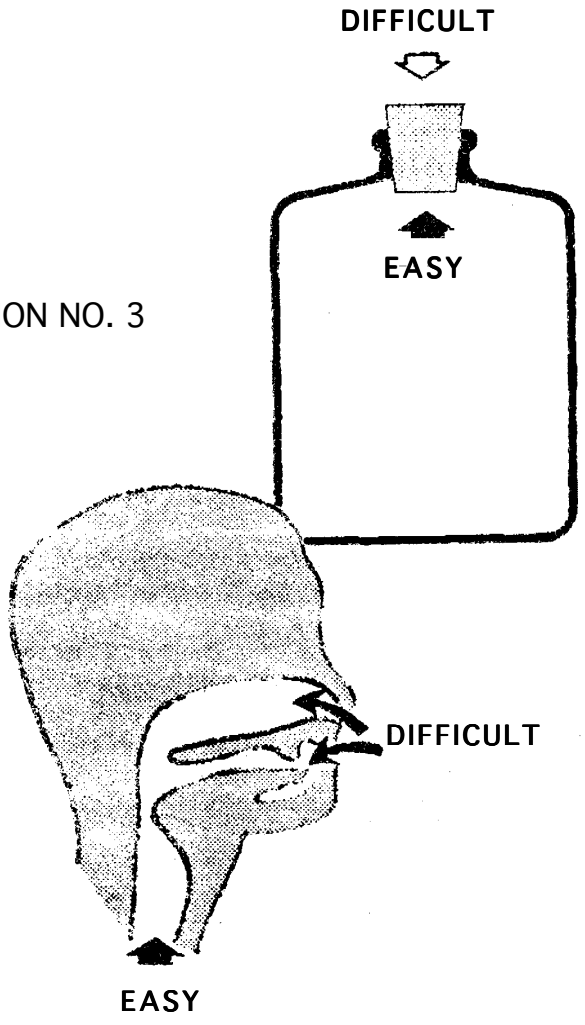


ILLUSTRATION NO. 2

ILLUSTRATION NO. 3



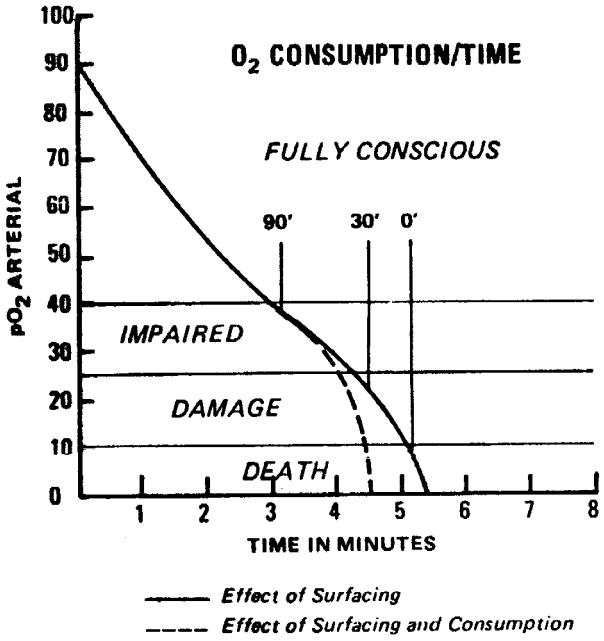


ILLUSTRATION NO.4A

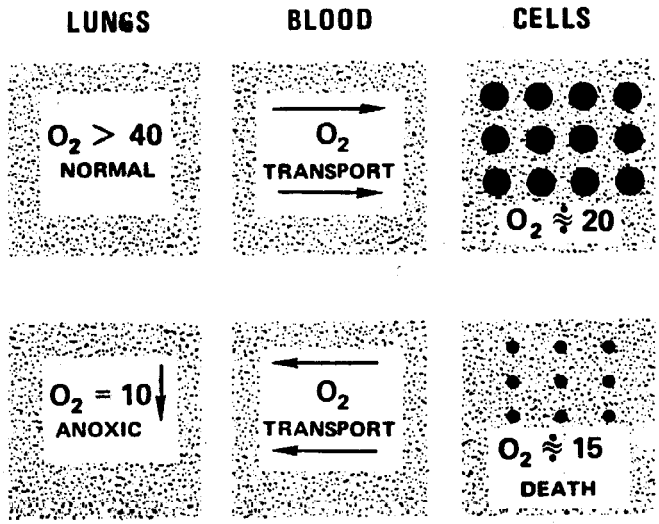


ILLUSTRATION NO.4B

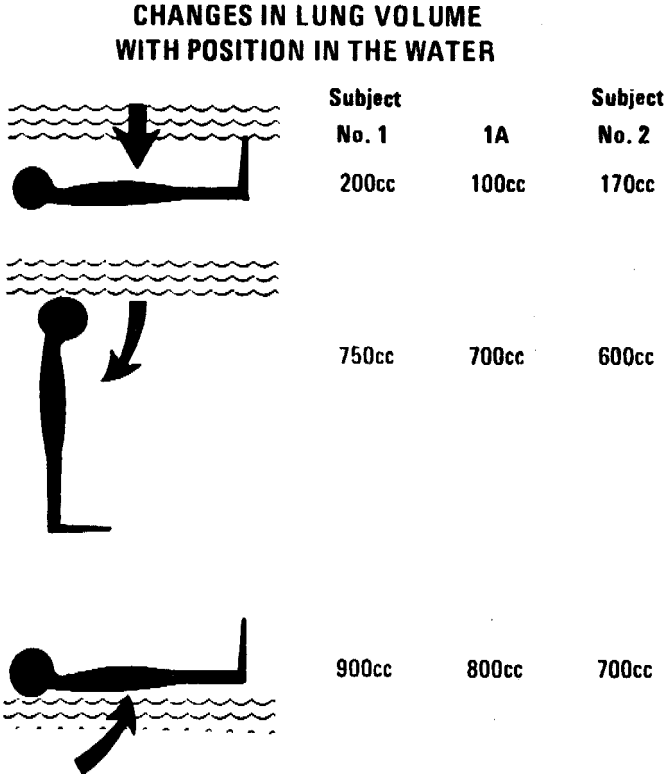


ILLUSTRATION NO.5

as hard as possible, by relaxing, the air comes out. This has been repeatedly verified on anaesthetized subjects. Air can't be forced into the lungs with the neck flexed but it can flow out.

ILLUSTRATION NO. 3

2. What about flow rate obstruction? Can expansion of the gas take place so rapidly that the respiratory tree is unable to handle the flow involved? Divers can achieve flow rates in excess of 400 litres per minute without encountering difficulty. To achieve these kinds of flow rates while surfacing a man with a 7 litre chest would have to ascent 30 feet to the surface in less than 1/60 of a minute or under 1 second, unlikely at any buoyancy. The fact that this can be safely accomplished is further substantiated by experience in the high altitude chambers where the rate of change for the same pressure differential is extremely rapid during a procedure known as explosive decompression. During this particular procedure the person does the equivalent of ascending 15 feet to the surface in less than 1/100 of a second.

3. Laryngospasm could be present especially if water has impinged on the vocal cords. Again the larynx is like a bat wing door, it opens in one direction even when in spasm. This, too, has been confirmed in anaesthetized subjects during operations. Embolus in the unconscious victim is probably near impossible but in a panic-stricken, conscious victim all sorts of voluntary mechanism exist, whereby be can prevent air leaving his chest. A look at data from high altitude chamber work where as many as 3-400 people a year undergo explosive decompression verifies this. In a normal decompression run a change in ambient pressure from 14.4 lbs. per sq. inch to 8.6 lbs per sq. inch takes place in less than 1/100 of a second which is the equivalent of an instant trip from 15 feet to the surface without ill-effects and without embolus occurring in any of the subjects. This indicates that the person in air who is not frightened about drowning and therefore not desperately hanging on to his air permits the air to escape and that it can do so passively and safely at very high rates. On the other hand there are many examples in diving where air embolus has been sustained with changes of as little as 8 feet to the surface, but in these instances it was in a subject who is in a foreign environment, panicky, and attempting to hold his air by voluntary mechanisms. In any instance where a diver is brought from the water and found to have an air embolus, it is my contention that the air embolus was sustained before unconsciousness ensued, not after. Even if laryngospasm is present at the outset, spasm will relax as the pO_2 decreases.

The effects of Boyle's Law as the diver surfaces results not only in the expansion of the gases in the chest but also in a fall in the respective partial pressures of the gases present including O_2 in both the victim's lungs and in the victim's blood (see Illustration No. 4 A). If the victim leaves the bottom at 30 feet with a pO_2 arterial of 40mm by the time he reaches the 15 foot level the pO_2 arterial is down to 30mm on the basis of pressure change along with no allowance for his consumption. By 2-3 feet he has a pO_2 arterial of below 25mm, a pO_2 level capable of producing permanent damage. If he started at a depth of 90 feet his pO_2 at 30 feet will be maximum of 20 and by 15 feet a maximum of 15mm of mercury at which point his blood may be giving off oxygen into his lungs. This state results in an almost instant depletion of blood and tissue stores. The blood literally takes O_2 from the tissues,

brings it hack to the lungs causing anoxic changes or death (see Illustration No. 4 B). To save the diver he must get through this zone as rapidly as possible. One foot per second or even 2 feet per second are obviously far too slow. At one foot per second it will take 90 seconds to get from the bottom alone. It becomes apparent that not only is the best source of air the surface, but that ascent should be as rapid as possible even if the rescuer cannot safely keep pace.

ILLUSTRATION NO. 4B

The suggested technique for saving an unconscious diver is as follows: a diver is found lying on the bottom, (eg. 60 feet) unconscious, regulator out. The weight belt and mask are removed, the diver is raised to a vertical position, his vest is pulled and he is allowed to ascend, the rescuer following, to institute artificial respiration on the surface. What is happening physiologically when the diver is rotated into the vertical plane? The graduent of pressure on the chest wall from the water will cause the lung volume to decrease and any excess air will come out of the mouth. This will purge the airway from below without the danger of driving water into the larynx and precipitating laryngospasm. As the unconscious diver begins to rise the expansion of air within the chest will continue until the pressure required to further expand the chest wall and offset the 30 cm of water gradient between the base of the lung and the mouth exceeds the pressure required to open the airway from below and allows the excess to stream out of his nose and mouth. When he arrives at the surface provided he is wearing a standard vest (which will float him on his back), he will first shoot from the water into the air then fall back into a horizontal float supported by his vest. The sudden removal of the 30 cm of water gradient due to his vertical position and immersion in the water will result in a passive inspiration of 6-900 cc of air without any assistance. This was verified by the following experiments.

First, relaxed subjects connected to spirometer recording air into and out of the chest were lowered horizontally into a swimming pool and the volume of air leaving their chests passively was measured. They were then permitted to hang vertically and again the air leaving the chest with this change in attitude was measured. Finally they were raised out of the water to a horizontal position and the air entering the chest measured and the following figures were obtained (see Illustration No. 4). The degree of relaxation of the subject must be suspect and so to be certain subject was anaesthetized, a tube put in his throat and he was put back into the pool repeating it all again which was done with the results labelled 1A (Illustration No. 5).

CHANGES IN LUNG VOLUME
WITH POSITION IN THE WATER

ILLUSTRATION NO. 5

The next illustration, No. 6 gives a comparison of the time required for each phase of the various methods of rescue and a comparison of some of the hazards. From the totals the advantages of what has been advocated in this discussion seem clear, in addition, it has been pointed out by references to the high altitude and anaesthetic experiences the hazards of embolus for the unconscious victim are vastly over-rated

compared to such hazards as fulminating anoxia, an inevitable consequence of ascent whose effects can be minimized only by the most rapid ascent possible. In addition, the victim receives that crucial first breath upon arriving at the surface as a bonus without any assistance from the rescuer.

In this brief report I have reviewed deep scuba rescue and have developed a simple, effective method for accomplishing deep scuba rescue in less than 90 seconds.

COMPARATIVE TIME COST

	New Way	Brand "X"
Remove Weights	1.5 sec	1.5 sec
Replace Regulator and Purge	N/A	5.0 sec + (20 sec)
Extend Head Squeeze Chest	N/A	2 sec May induce vomiting
Pull Vest	0.5 - 1.0 sec	N/A
Invert Victim	N/A	2-5 sec Aspiration
Trip Up (30 ‘)	4 sec or less	15-20 sec
Approx. Time to (1) First Breath (2) Start AR	 6-8 sec 10-20 sec	 25-33 sec 25-33 sec

ILLUSTRATION NO. 6

* * * * * * * *

Brief Profile

Dr GD Harpur became especially interested in the correct response to finding that one’s buddy had lost consciousness when he heard of an incident in 1972 where the victim survived but the assisting diver held his breath while excited in the ascent and suffered an air embolism that left a residual paralysis. Another incident later in the year again resulted in complete recovery of the victim but an excited “bystander” followed too rapidly up the last 20 feet and suffered a fatal air embolism. The significance of the unconscious/ survival and conscious/air embolism relationship in these incidents led to the formulation of this article. The views here expressed are worthy of wide circulation.

* * * * * * * *