4. HYPOXIA IN BREATHHOLD DIVING

- Bob Thomas

Any decrease in arterial oxygen concentration to 35mm Hg or less will induce some impairment of consciousness in a diver, and this may lead to fatal sequelae. The hypoxia which occurs in breathhold diving can become a real hazard under certain conditions, and these will be elaborated in detail.

Normally, the breaking point of a breathhold dive occurs when the P_aCO_2 reaches approximately 50mm Hg. If for some reason this threshold is increased, then the breathhold dive may be prolonged for a sufficient degree to result in a fall in P_aO_2 to a level which would then be unacceptable for consciousness. There are several ways in which the breaking point threshold may be increased, ie. the desire to breathe may be temporarily overcome by the use of these diversionary tactics. These include:

- swallowing
- diaphragmatic movements
- exhalation
- adaption
- volition (eg. spearing a fish)

The following sequence of events illustrates how hypoxia may develop:

1. Initial surface breathing, normal alveolar oxygen pressure (P_AO_2), P_aO_2, P_ACO_2, P_aCO_2.

2. With descent there is a decrease in lung volumes and a subsequent increase in the partial pressures of the contained gases (Boyle's Law). These higher partial pressures of O_2 then allow O_2 uptake by the blood to continue for a longer period than if breathhold had occurred at the surface. There is often an early mild desire to breathe during descent but this soon wanes. Transfer to CO_2 from the blood to the lungs is reversed across the alveolar membrane due to the increased P_ACO_2.

3. During the course of the dive (at depth) there is a continued removal of O_2 from the lungs, and its subsequent utilisation by the body. This may be increased by excessive demand as with strenuous exercise. Exercise also results in an increased production of CO_2 and lactic acid, and the P_aCO_2 equilibrates with the P_ACO_2.

4. As the P_aCO_2 and P_ACO_2 continue to increase during the dive, an increased awareness of nearing the breaking point of the

breathhold occurs, ie. there is an increasing urge to breathe. This sensation may be diminished by using such diversionary tactics as mentioned previously.

5. Relief from this sensation may also be obtained by ascent. This in effect will increase the lung volume, causing a concomitant fall in the P_ACO_2 and thence P_aCO_2, unless the ascent is very slow. However, the P_AO_2 and P_aO_2 also fall, and although the P_AO_2 may have been sufficient at depth to maintain adequate oxygenation, a fall to a lesser concentration may precipitate hypoxic loss of consciousness. This, in fact, does occur, and the loss of consciousness almost always has occurred during the ascent phase of the breathhold dive. If no loss of consciousness should occur during the ascent, then it may still become apparent immediately following surfacing, because the circulatory delay in correcting the hypoxia of ascent may be sufficient to allow further reduction of the P_aO_2 to an unacceptable level.

Hyperventilation prior to breathhold diving is a common manoeuvre used to reduce the P_aCO_2, and thence a longer time will elapse following the commencement of the dive until the threshold P_aCO_2 of the breaking point is reached. This increased interval, although allowing a longer submergence time, may also permit a dangerous degree of hypoxia to develop, such that either:

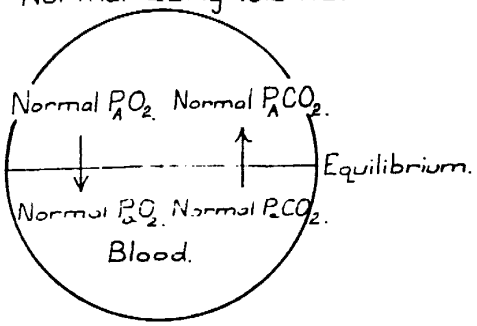
- loss of consciousness may occur well before the P_aCO_2 has increased to reach the breaking point threshold, or

- loss of consciousness may occur with ascent as discussed before, or

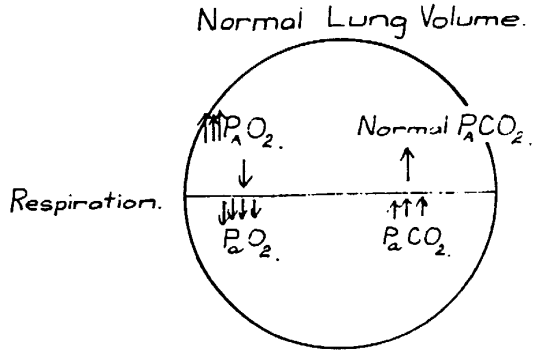
- ventilation may be stimulated by hypoxia whilst still ascending.

Consequently, the use of hyperventilation techniques should be avoided by all breathhold divers. Unfortunately a lack of significant statistical information does little to assist in warning both the trained and the novice diver of the inherent dangers.

The following diagram illustrates the development of hypoxia with and without prior hyperventilation.



(With prior hyperventilation P_ACO_2 and P_aCO_2 are greatly diminished. P_AO_2 is slightly increased)

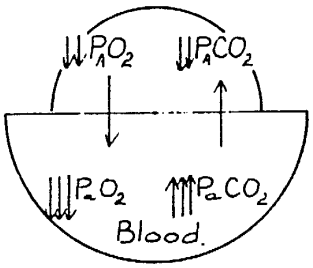


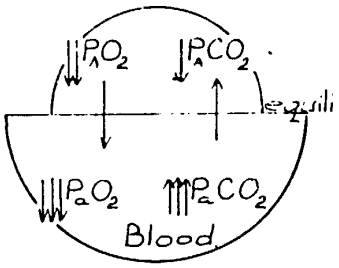
(Hypoxia may develop if there is some delay in increasing P_aO_2 (ie. circulatory.)

Surface

Increasing lung volumes.

Descent.



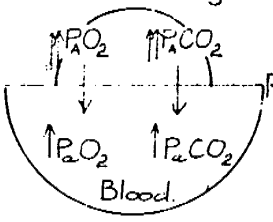


(Hypoxia may precipitate unconsciousness. This is more likely if P_aO_2 is greatly reduced by prolonged utilisation allowed by hyperventilation.)

Rapid Ascent.

Slow Ascent.

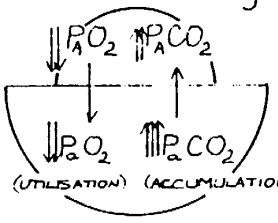
Reduced lung volumes.



Reversal of CO_2 flow.

Duration at depth.

Reduced lung volumes.



(With hyperventilation the accumulation of P_aCO_2 will need longer time before reaching threshold levels. This may permit a dangerous drop in P_aO_2.)