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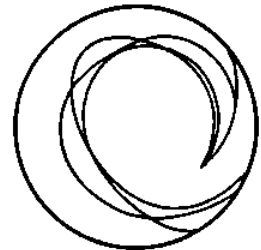
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DIVER EDUCATION SERIES

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Respiration and the Diver

Lee H. Somers



Michigan Sea Grant College Program

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RESPIRATION AND THE DIVER

Lee H. Somers, PhD

REVIEW OF FUNDAMENTAL CONCEPTS

Respiration is generally thought of only in terms of "breathing." However, the process of respiration also includes the utilization of oxygen and various exchanges of gases which take place throughout the body as a part of the metabolic process. Gas exchange associated with breathing is sometimes considered as "external" respiration whereas other aspects are identified as "internal" respiration.

Ventilation of the lungs is achieved by changing pressure within the pleural space. Inspiration is achieved by muscular movements which elevate the ribs and depress the diaphragm. This lowers the pressure in the pleural space and air at a higher ambient pressure flows into the lungs in response to the pressure gradient until equilibrium is reached. The air flows from the mouth and nose to the lungs through the trachea which divides into a network of tubular passages called bronchi. The bronchi divide into smaller bronchioles which carry air to the numerous tiny air sacs, or alveoli, where gas exchange between the lungs and the pulmonary capillaries takes place. Expiration is achieved by simply stopping inspiration. As the muscles relax, the elastic recoil of the lungs forces the air out.

Part of the pressure generated by the respiratory muscles is used to overcome flow resistance in the airways. Flow resistance is related to flow rate and the pressure gradient between one end of the tube and the other. During periods of relatively normal breathing, the pressure generated by the respiratory muscles is used primarily to overcome the elastic recoil of the lung. However, during active ventilation, as in exercise, flow resistance becomes a much more significant factor and necessitates that expiration be achieved by contraction of expiratory muscles. Maximum ventilation is limited by flow resistances, specifically during expiration.

When breathing at one atmosphere, normal humans, even at maximal exercise, utilize only 50 to 60 percent of the maximum voluntary ventilation. Maximum ventilation is a function of flow resistance which, in turn, is dependent on gas density. In humans, flow in large airways is generally considered as turbulent and is inversely proportional to the square root of gas density.

When the gas density is increased fourfold (as at 100 fsw or 4 ata), turbulence and resistance within the airways reduces the flow to approximately one-half normal. However, at a depth of 100 fsw exercising subjects regularly approach 100 percent of

their maximum voluntary ventilation as compared to 50 to 60 percent at sea level. Consequently, at 100 fsw there should be virtually no ventilation-imposed exercise limitation in the air breathing diver [1].

All underwater breathing apparatus has discernible resistance to gas flow and breathing. Some scuba constitute a formidable workload on the respiratory system. Although modern diving apparatus does have considerably better flow properties than many earlier models, some modern open-circuit scuba regulators have unsatisfactory flow properties at depths in excess of 100 fsw during periods of maximum ventilatory requirements.

The ventilatory control system responds to arterial oxygen and carbon dioxide tension. The principal sensing site or respiratory center, in the area of the medulla oblongata of the brain, is sensitive to the level of carbon dioxide and acid in the blood. This center controls rate and volume of ventilation. Peripheral chemoreceptors, located chiefly in the carotid bodies, monitor the level of oxygen and carbon dioxide in the blood leaving the lungs. These sensors respond primarily to hypoxia (depressed oxygen tension). Hypercapnia (elevated carbon dioxide tension) is a powerful stimulus to respiration. Hypoxia is a relatively minor stimulus, and the arterial oxygen tension may become critically low before the chemoreceptors send impulses to the respiratory center. Increased airway resistance, internal and external, depresses the ventilatory response to hypercapnia and, to a lesser degree, hypoxia.

Respiratory sensitivity is reduced by a number of conditions encountered by divers at elevated ambient pressure. Of particular significance is low breathing rates, higher oxygen partial pressure, and increased gas density. Experienced divers appear to have reduced ventilatory responses to both carbon dioxide and exercise. Although carbon dioxide retention does tend to conserve air and limit ventilatory effort, the dangerous implications of carbon dioxide poisoning are significant.

Normally, experienced divers tend to ventilate less during exercise than nondivers. Scuba divers normally take long, relatively deep inhalations followed by a long exhalation, particularly during periods of low exercise. Underwater a diver may breathe at a rate of 6 to 10 cycles per minute compared to 10 to 20 cycles per minute on the surface. Breathing pattern modifications resulting from voluntary prolonged inspiratory breath-holds, anxiety, physical stress and equipment insufficiencies can have adverse effects on the diver.

HYPERVENTILATION SYNDROME

Hyperventilation initiated by anxiety and/or physical stress may result in unconsciousness or muscle spasms as possible consequences of excessive depletion of carbon dioxide with

subsequent acid-base imbalance in the blood and body. The diver may not be aware of his pending problem. In water this can result in drowning. Some individuals are more susceptible to low CO₂ tension (hypocapnia) than others; however, loss of consciousness and muscle spasms could probably be induced in almost anyone with sufficiently prolonged hyperventilation.

Both scuba and surface-supplied divers should be aware of the problems associated with hyperventilation. If the diver notices that he is involuntarily hyperventilating, he should take immediate steps to slow his breathing rate. A scuba diver should notify his buddy, and if the situation cannot be corrected, promptly ascend. When he reaches the surface, he should inflate his buoyancy system. Don't attempt to swim to the boat or shore unaided since unconsciousness may be imminent. A tender should continuously monitor the diver's breathing for signs of hyperventilation. If the diver starts to hyperventilate, he should be asked to stop work and rest. Holding his breath for short periods will aid in replenishing low CO₂ levels and possibly avert further complications. Drowning and the hyperventilation syndrome are discussed in detail by Prasser [2].

HYPERPNEA-EXHAUSTION SYNDROME

Various problems in diving such as equipment malfunction, reaction to venomous animal wounds, cold stress, exhausting swims, etc, may cause a diver to panic. A frequent manifestation of panic is rapid, shallow breathing (hyperpnea), resulting in insufficient ventilation of the lungs. Subsequently, there is an accumulation of carbon dioxide in the lungs, blood, and body tissues (hypercapnia). The diver's situation is further complicated by possible decrease in buoyancy due to inadequate inflation of the lungs. The onset of the hyperpnea-exhaustion syndrome is indicated by rapid, shallow breathing; dilation of the pupils; inefficient swimming movements; and signs of exhaustion. The diver will experience anxiety and exhaustion. Collapse from exhaustion, unconsciousness, and subsequent drowning may follow. Divers exhibiting the signs or symptoms of this manifestation should immediately terminate the dive, surface, and inflate buoyancy compensator. Tenders and diving partners should watch for signs of distress. This condition may be responsible for some near-drownings and drownings in scuba divers who were swimming on the surface when they apparently lost consciousness.

OVEREXERTION AND EXHAUSTION

Nearly everyone has experienced the "out-of-breath" feeling, from working too hard or running too fast. It is possible for a person to exceed his normal working capacity by a considerable margin before the respiratory response to overexertion is apparent. The end result is generally shortness of breath and fatigue. On land, this presents little problem.

Underwater (under increased ambient pressure), the problems of exertion are modified by several factors and are considerably more serious. Even the finest breathing apparatus offers some resistance to the flow of air. As the depth increases, so does the density of air, and consequently, it moves through the body's airways with greater resistance to flow. When shortness of breath and fatigue are brought on by overexertion, the diver may not be able to get enough air. The feeling of impending suffocation is far from pleasant, and it may lead the inexperienced diver to panic and a serious accident.

Man's ability to do hard work underwater has definite limitations, even under the best of conditions. Many situations can lead to exceeding these limits. They include:

- * working against strong currents;
- * prolonged heavy exertion;
- * wasted effort;
- * breathing resistance, especially with poorly designed and maintained breathing apparatus;
- * carbon dioxide build-up;
- * insufficient breathing medium or contamination; and
- * excessive cold or inadequate protection.

The diver will realize that he has overextended himself by recognizing such indicators as labored breathing, anxiety, and the tendency toward panic that accompanies the overexertion feeling.

If the diver feels the typical "air hunger" and labored breathing starting to appear, he should do the following:

- * Stop, rest, and ventilate to get a maximum flow of air. Breathe deeply. Ventilating helmet or mask with free flow (surface-supplied divers).
- * Inform the "buddy" or tender.
- * Do not surface rapidly -- terminate the dive with a slow, controlled ascent.
- * Upon reaching the surface, the diver should inflate the buoyancy compensator and return to the boat or shore, or if too exhausted, ask for buddy assistance or signal for an immediate "pick-up."

The "buddy" and surface crew should:

- * render all possible assistance;
- * watch for signs of panic that might lead to a serious underwater accident;
- * help diver aboard; and
- * provide rest, warmth, and nourishment.

Overexertion can be prevented if the individual knows and observes his limitations, takes into consideration the working conditions, and plans the diving operation accordingly. For example, plan the dive so that you can move with the current and not against it. Divers should keep themselves in excellent physical condition. The equipment must always be maintained in excellent working condition. Be alert for signs of fatigue!

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1. **Anthonisen, N.**, "Respiratory System in Diving," pp. 35-48 in Strauss, R. (ed.), Diving Medicine (New York: Grune and Statton, 1976).
2. **Prasser, D.**, "Drowning and the Hyperventilation Syndrome," California Medicine 3(4):322-24 (1969).