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Review of Human Physiology in the Underwater Environment

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ABSTRACT

Since before centuries, human tries hard to explore underwater and in 1940's human-introduced an important and revolutionary gear i.e. scuba that allowed human-made long interaction in the underwater world. Since diving using pressure gas under pressure environment, it should be considered to remember gas law (Boyle's law). The gas law gives a clear understanding of physiological consequences related to diving diseases such as barotrauma or condition in which tissue or organ is damage due to gas pressure. The organ which has direct effect related to compression and expansion of gas were lungs, ear, and sinus. These organs were common and potentially fatigue injury for a diver. In this article we shall review the history of scuba diving, physical stress caused underwater environment, physiology adaptation of lung, ear, and sinus, and diving disease.

Keywords: Barotrauma, Boyle's law, Scuba, Barine, Physical stress

INTRODUCTION

The underwater world is a place where many people dream to explore it. The limitation of human hold breath and endurance into underwater became a big challenge. Many designs diving equipment has been designed by artist or scientist, started around 332 BC that Alexander the Great used a bell diving during the siege of Tyre that called as Colimpha [1]. In the 14th centuries, Leonardo da Vinci made a bag's like mask connected bamboo tube into bell containing air that floats in the surface of the water. An Italian Gulielmo di Lorena made a bell for diving in the 1531 AD, and an astronomer Edmond Halley designed a diving bell which had air supply that brought a diver can dive in the 18 m of seawater for 1.5 hours [1,2]. In the 19th century, a German-British engineer, Augustus Siebe, introduced a close diving helmet which was made from copper. The helmet was attached on dress apparatus that keep diver dry during diving [3]. In the 1943 Jacques Yves Cousteau delivered important and revolutionalized a self-contained underwater apparatus (SCUBA). He and his partner, Emile Gagnan, invented buoyancy control device (BCD), through which the diver can control ascent and descent in the water [4].

The underwater environment is unkind for human where the water is dense than air that caused poor sound and visibility, high pressure with the increase of depth also decreasing temperature. Those are challenges for a diver and is called as underwater environment stress that is categorized in the 3 groups: physical, physiological and psychological. The physical stress came from properties of water such as the effect of hydrostatic pressure, buoyancy and viscosity, and thermal properties of water. A lifting power of an object in liquid medium or buoyancy reflecting a sink or floating an object in the water (Archimedes law). The density of water not only influenced buoyancy but also interfered object movement, in another word effect of water thickness that causes resistance in water moving called viscosity. For divers challenge related to water viscosity were current, swell, waves, surge, and turbulence. Water has 1000 times greater specific heat and can conduct 25 times faster heat away from an object.

Physiological stress is caused by the water environment related to ventilation process in the human body through breathing oxygen and exhaling carbon dioxide. Lack of oxygen supplied to the body will affect light-headedness and consciousness. Carbon dioxide has resulted from the metabolic process after oxygen interacted into substances inside of the body. CO_2 exhaled from lungs into the environment, short breath and sedation will accumulate a lot of number carbon dioxide resulted in toxicity. The underwater environment seems a strange place for a diver that their vision and hearing sense will most be affected. Vision need for orientation during diving activities, but the light moving faster in

the water and distorted vision a diver. Hearing is also altered in the water where sound conduction is faster about 25 times than on the air which results in impairment of sound acuity. Limitation of senses in a new environment during the dive, a diver can loss of orientation to the real direction (Figure 1).

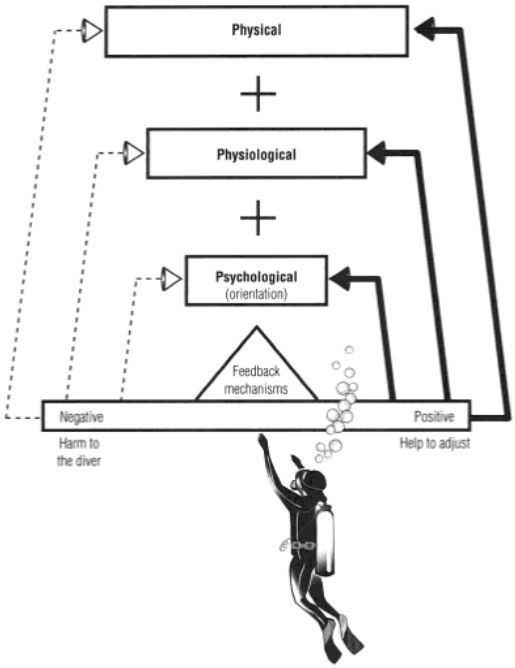

Figure 1 Possibility stress from the underwater environment [5]

Physiological Adaptation

Lung: Respiratory system in human start from mouth and nose passes pharynx to the windpipe called the trachea. Trachea split into 2 tubes as bronchi, in the lower part bronchi divide into a smaller part called as bronchioles and alveolar duct. The average of total lung capacity for man is 4.7 litre and is less for the woman. Figure 2 stated that without SCUBA the volume of lungs will decrease up to one-fourth of a diver descent into 30 m.

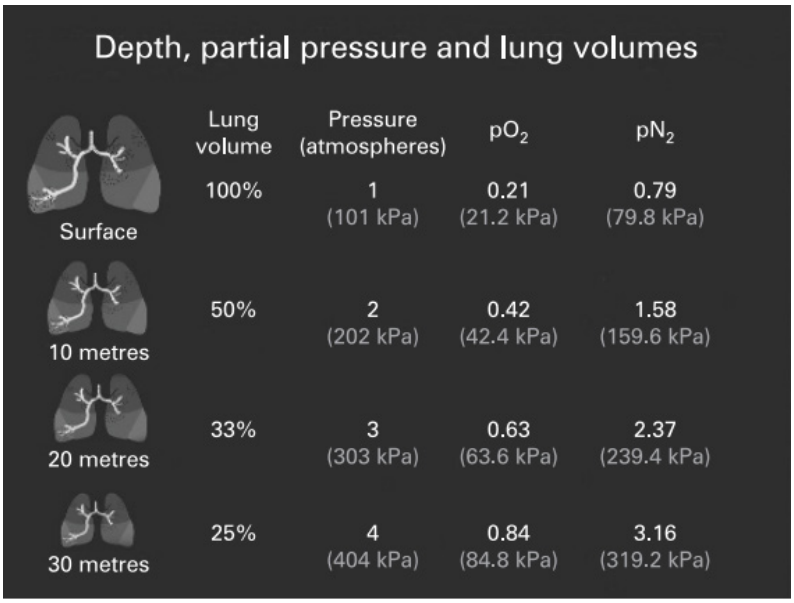

Figure 2 Lungs volume [6]

Ear and sinus: The ear has a function to hearing and the role of the balance system in human. The human ear has 3 different spaces: external, middle and inner ear [7]. Sound will catch in an outer canal and if the pressure in the middle ear matches with pressure air in the environment and Eustachian tube, it is responsible to regulate it. When descent during diving the pressure in the outside eardrum is higher than the pressure in the middle ear make eardrum flex inward [8] (Figure 3).

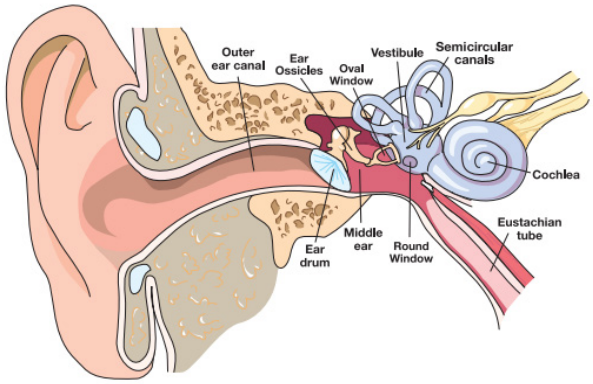

Figure 3 Ear anatomy [14]

Sinus is a cavity in human organ, during diving 4 sinuses (Paranasal sinuses) may affect causes of water pressure. They are couples frontalis sinus, maxillary sinus, ethmoid sinus, and sphenoidal sinus. All of them connected each other through small tubular openings. , the sinus Ostia, which drain into different regions of the nasal cavity [9,10]. The maxillary sinuses are known as the largest sinuses were discovered beneath the eyes in the maxillary bones. The frontal sinuses are located superior to the eyes within the frontal bone. The ethmoid sinuses found in the bone between the nose and eyes, while sphenoid sinuses located under sphenoid bone (Figure 4). The functions of paranasal sinuses itself unclearly known but their present have important role such as decreasing weight of the skull, increasing voice resonance, and immunology defenses [9].

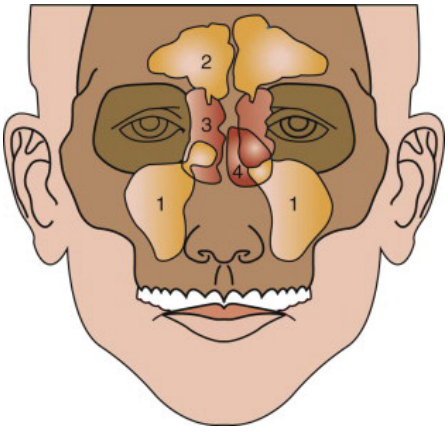

Figure 4 The maxillary sinus (1), Frontal sinus (2), ethmoid sinus (3), sphenoid sinus (4) [9]

Diving Diseases

Barotrauma: During diving activity using scuba diver breaths high-pressure air from the tank through the regulator in the high-pressure place. Depth influence the underwater pressure as Boyle law state that at a constant temperature the pressure (P) of a gas inversely with the volume (V) that applied in formula $P_1V_1=P_2V_2$ [11,12].

This law relates of all barotrauma (pulmonary, ear and sinus), when a diver decent into 10 m (33 ft), his body pressure 2 atm and volume gas (lung) decreases by half (Figure 2 and Table 1). If he inhaled air to fill his lung at a 10 m, the volume of gas will expand double. According to Lynch, et al., [12], barotrauma is defined as the damage of human organ (tissue) caused by the inability of the body to equalize pressure in a gas-filled space. And the case of barotrauma in ears and sinuses are very common for diver [7].

Ear barotrauma: Middle ear squeeze is the most common diving injury, about 30% of new diver experience it because of fault during the equalizing process [12]. The difficulty in equalizing can be minimized by slowly descending (1-2 m above) and equalizing using the jaw thrust or nose exhalation. Another way is using an earplug to delay air movement into the external ear canal and give chance to the eustachian tube to equalize air pressure.

Sinus barotrauma: Sinuses are covered by muscles and blood vessel, in normal condition, sinus automatically changes their pressure (equalize) by the free passage of gas (in and out) through the opening (Ostia) when diver descent or ascent. The opening of the sinus is blocked due to several obstructions. Some obstruction came from inflammation (sinusitis), tissue fluid, blood, and mucous. During descent gas inside sinus will be compressed and give a sense of pain for the diver. And when diver ascent blood or tissue fluid inside sinus, it will eject into nose or throat due to gas expanding [13].

Table 1 Effects of depth on ambient pressure [12]

Depth (m/ ft)	Pressure (atm)	Mercury	PSI
0/0	1	760	14.7
10/33	2	1520	29.4
20/66	3	2280	44.1
30/99	4	3040	58.8
40/132	5	3800	73.5

Pulmonary barotrauma: Pulmonary barotrauma (PBT) is alveoli rupture during ascent. Boyle's law stated that during ascent pressure is reduced and contrary volume of gas in the lung will expand. If a diver breath a compressed air at depth and keep it during ascend, the air in the lung will expand as ambient pressure fall. In some case, air will enter into the vein and goes into the left heart, and make air bubbles trough arterial circulation and obstruct the blood flow into the brain and cause stroke-like event (Figure 5)[12,13].

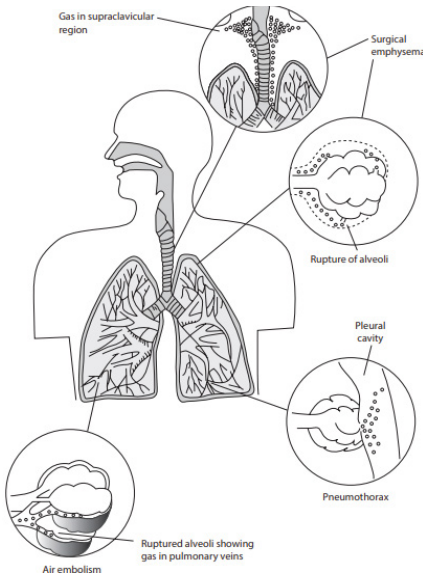

Figure 5 Pulmonary barotrauma during ascending [13]

Decompression Sickness (The bends): Decompression sickness (DCS) is a disease due to bubbles formed from dissolved gas in blood and tissue following a reduction in ambient pressure. During diving, inert gas (primarily nitrogen), dissolved into tissue and after much time becomes saturated. As diver is ascending, the nitrogen will be supersaturated and form a bubble in the blood and lungs which may result in the decompression sickness. The symptom of this disease may be seen immediately after diver comes on the sea surface and in some case, it may delay up to days [6]. Later DCS has been classified into DCS type I and DCS type II. DCS type I is a mild disease in which local joint pains, skin rashes and swelling on a certain area. DCS type II is a serious condition which usually damages the spinal cord causing abnormal dermal sensation (paraesthesias); paraparesis (partial paralysis on the leg) and paraplegia (leg paralysis).

CONCLUSION

Diving is relatively new and quite popular in the last 5 decades. Interaction of human to the underwater environment gives a lot of challenges on physical, physiological and psychological to the diver. So, this activity is always related to high risk and is dangerous which has the potential of death. Understanding physic law in gas pressure will increase our knowledge of the effect of human physiology at its limits.

DECLARATIONS

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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