PHYSIOLOGY OF APNEA WITH EMPHASIS ON DYNAMICS OF 0_2 AND $C0_2$ IN THE ORGANISM AND SAFETY OF DIVE

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Abstract
Free diving (apnea) is the only purely anaerobic activity that man practices. During dives on his disposition remains a quantity of air and from it oxygen, which he has inside his lungs, bloodstream and tissues during the last breath before diving. During dives he exploits oxygen for metabolic processes and additional muscle work and its partial pressure is constantly falling while at the same time there is an increase in the partial pressure of carbon dioxide. When diving in a liquid medium (water), under the action of hydrostatic pressure, he is in a constant state of hypoxia and the gases in the body of a free dive are under pressure, or their partial pressures, by following certain rules of behavior of gases under pressure, regulating the duration of the apnea, and thus the safety of the dive. The aim of this paper is to become closely acquainted with all the facts about the physiological processes during the dives taking place in organic systems of free divers as to allow safe diving and avoid incidental situation, which has enabled the synergy of medical and technical sciences in explaining this complex and dangerous human activity.

Key words: *apnea, respiratory system, partial pressure of oxygen, partial pressure of carbon dioxide, dynamics of gases.*

Introduction

Snorkelling, apnea, is the most widely used technique of diving. In its original form is performed without any equipment. With adequate mental and physical fitness, individuals can dive to depths of up to 200 meters, and stay under water for several minutes. Although diving in apnea is the most widespread and technically simplest form of diving, from a physiological point of view it is the most complex and unknown and contains traps. It sounds unbelievable and absurd that in apnea often victims are experienced and very well trained divers with long history of diving. The reason is that they hold their breath the longest and achieve maximum depth but from defective knowledge and overconfidence do not comply with the strict regime brought to the incidental situation, most often with a fatal outcome (Drviš, I., Katowice, D., Viskić-Štalec, N., Grcic-Zubčević, 2006, Lozovina, N., 2001, Gošović, S., 1956). It is prohibited to engage in dives before the diver is thoroughly acquainted with the physiology and pathology of apnea, as well as measures to prevent incidents (drowning threatening). Training of a free diver starts by introducing the process of breathing by which living organisms carry out gas exchange with the environment. In order to fully understand the process of breathing is necessary to know the respiratory detail, their construction and function, both at atmospheric pressure and elevated pressure conditions which increase in depth increases. The different behavior of gases and the differences in their partial pressures, in particular oxygen and carbon dioxide in certain circumstances can cause incidents with unlikely outcomes including death. It is important therefore to know the gas legality by which gases behave, particularly in terms of dives. Ultimately, when we meet with all these facts, it is necessary to examine in detail all the changes taking place within the organism. A dive in apnea leads to differences in lung volumes and lung capacities, and special attention should be paid to the dynamics of oxygen and carbon dioxide in inspirational apnea of which is discussed in this paper. When diving in apnea, if you ignore the warning '' hunger for air and the need for breath '' and went on to sleep, and if there is a critical level, it is very likely that the diver will fail to come up to the surface. In these cases it is necessary to know the methods and ways of reviving, be it on a blue or pale drowning man. The purpose of this paper is to get closely acquainted with all factors of physiological processes during the dives take place in organic systems of divers as well as security measures that allow safe diving within recreational, sporting or professional snorkelling. All living organisms carry out the exchange of gases with their surroundings. This exchange is known as breathing and respiration. Life support person inhales air (a gas mixture consisting of nitrogen, oxygen, carbon dioxide, noble gases and water vapor). Breathing in this mixture in the pulmonary diffusion process through the alveolar-capillary membrane and to which the haemoglobin binds the oxygen, was supplied with oxygen through the bloodstream all tissues of any working of the metabolism in the sleep mode or the additional work of any kind.

The breathing process

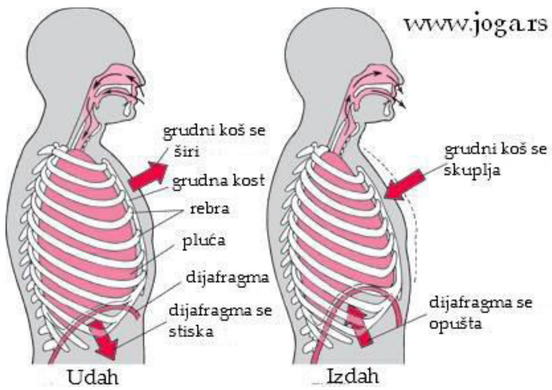
Breath is the oxygen transfer from the air cells of the tissue and the transfer of carbon dioxide in the opposite direction, e.g. cells from tissue to air. It is the contrast biochemical definition of respiration, which is related to cellular respiration: the metabolic process by which the organism takes energy to the reaction of oxygen with glucose to give water, carbon dioxide and adenosine triphosphate (ATP) - energy. Although physiologic respiration is necessary to sustain cellular respiration and thus the life of living creatures, different processes: cellular respiration takes place in individual cells of living organisms, and is physiologically concerned by the flow of breath and a metabolite of the organism and the external environment. In single-celled organisms, simple diffusion is sufficient for gas exchange, each cell is always in contact with the external environment, the short distance travelled by the gases must pass. In return, complex multicellular organisms such as humans have a greater distance between the environment and their internal cells, and for this reason the respiratory system required for effective gas exchange. Respiratory system operates in line with the vascular system of the gases in the tissue.

There are four main functions of respiration:
Pulmonary ventilation, which means the air flows in both directions between the atmosphere and the alveoli,
Diffusion of oxygen and carbon dioxide between the alveoli and blood,
Oxygen and carbon dioxide in blood and body fluids and body tissues give the regulation of ventilation and other aspects of respiration.

Breathing represents a spontaneous, rhythmic mechanical process. Muscle contraction and relaxation during breathing by the moving gas from the atmosphere into the lungs, and vice versa, which give the body the gaseous medium for the exchange of gases. It consists of two actions, inhalation and exhalation.

External breathing takes place in the alveoli of the lungs. Air, oxygen-containing atmosphere from a mechanical process of breathing has lung alveoli. From the inspired air into the alveoli, oxygen diffuses into the blood stream. At the same time, the diffusion of carbon dioxide from the venous blood passes the alveoli where the exhaled air to leave the lungs. The cycle of breathing is an unconscious process that is constantly repeated, unless it is due to disturbance of consciousness disturbance occurred in its regulation.

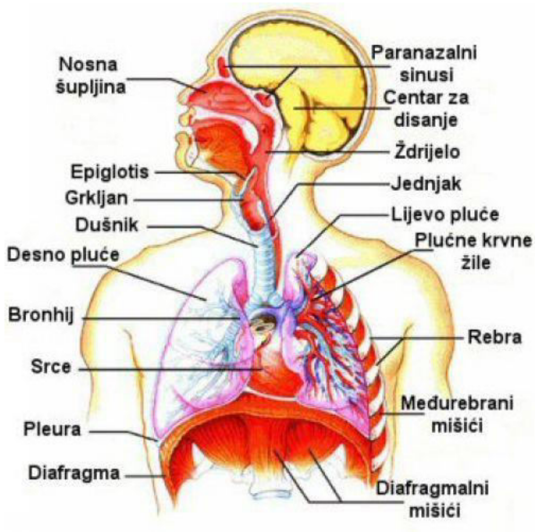
External breathing takes place in two phases: The active phase- Inhalation representing movement of air to the lungs. It is caused by the expansion of the chest wall and by lowering the diaphragm. Lung volume increases and therein establishes a low pressure. Because the higher pressure from the outside, the air penetrates into the lungs. In the course of quiet breathing intrapleural pressure (fluid pressure in the narrow space between the lung and pleural empyema thorax) below atmospheric at the beginning of inhalation is about -2.5 mm Hg and reduced to approximately -6 mmHg at the end of inhalation. During this time the pressure in the lungs varies in the range of 0 to -1.2 mmHg, e.g. becomes slightly negative. For maximum puff the diameter of the chest increases by 20%. And the average number of normal breaths per minute is 12, and the volume of air inhaled in one breath is about 500 ml. Respiratory minute volume or amount of air that passes through the lungs in one minute is thus an average of 6 liters. In the passive phase of the external breathing - exhaling, the diaphragm is lifted and the chest walls are tapered, leading to increase of pressure inside the lungs. Once the glottis opens, the pressure inside the lungs pushes the air, together with the liberated carbon dioxide in the blood back into the atmosphere.



Picture 1. Representation of inspiration and expiration (http://www.joga.rs/disanje).

Internal respiration is a process that takes place at the tissue and cellular level, in which oxygen-rich blood oxygen use, and returning it to carbon dioxide. This mechanism is known as the metabolic process of energy production necessary for life. Internal or cellular respiration takes place gradually, in several steps, which results in a conversion of energy stored in molecules of glucose into usable chemical energy in the form of ATP. The nervous system adapts to the size of alveolar ventilation needs of the organism. As a result, the pressures of oxygen and carbon dioxide are a minimal change in the heavy load of the respiratory system. The respiratory center of the medulla oblongata and pons (bridge-connects on the medulla midbrain), and the regulation of respiration to be continuous sending pulses. Respiratory center is divided into three major classes of neurons: dorsal respiratory group of neurons that monitors respiration rate and breath rate, ventral respiratory group of neurons that can cause the inhalation and exhalation, and the pneumotaxy center which limits the duration of inhalation and increasing the frequency of breathing. Chemosensitive area of the respiratory center is sensitive to changes in the partial pressure of carbon dioxide and the hydrogen ion concentration in blood, and the area other parts induces the respiratory center. In addition to the respiratory center, respiratory activity and control of the peripheral chemoreceptors They are important to detect changes in blood oxygen concentration, and although less responsive to changes in the concentration of carbon dioxide and hydrogen ions, and they send nerve signals to the respiratory center (Bucks, D., 2015). The ultimate goal is maintenance of favorable breathing oxygen concentration, carbon dioxide and hydrogen ions in the body fluids. Increase in carbon dioxide or hydrogen ions affect the respiration so as irritating to the respiratory center and cause the removal of excess respiratory gas acceleration. Control of carbon dioxide can be feedback mechanism, so that in the course of pneumonia, emphysema and other lung diseases, this system can increase the alveolar ventilation 5-7 times. (Boskovic, M., 1964, Kleoncic, M., 2007., Hrašćan, R., 2915., Guyton, A.C.; Hall, J. E., 2012).

For safe and smooth diving in apnea, it is crucial to understanding the structure and function of the respiratory organs. The respiratory system consists of the airways, and organs that bring the atmosphere into the body. It is divided into upper and lower respiratory system. Upper respiratory tract to form the nose, paranasal sinuses, pharynx (lat. Pharynx) and the larynx (lat. Larynx) and the bottom constitute the trachea (lat. Trachea), bronchi (lat. Bronchi) and lung (lat. Pulmones).



Picture 2. Composition of respiratory organs (http://www.ospopovaca.skole.hr/8bd/organi/documents/29.html).

The oral nasal passage consists of the lips, mouth, nostrils and nasal cavity. Nasal passage is lined with mucosa, such as the ciliary epithelium covered (with hair cell layer), whose primary role of filtering and humidifying the air. Mechanical impurities from the inspired air are retained in the oral cavity and the nasal epithelium in a moist, where the mechanically removed from the nose and mouth (coughing, sneezing, saliva) or ingestion. In the nose and mouth air is heated and moistened by the steam, before it reaches the lungs. If man breathed air through the common pipe, dry cool air reaching the lower parts of the lung, was favorable to infection. The air that enters through the nasal cavity is better filtered air of one who enters through the mouth. The throat is a body cavity that connects to one side of the oral cavity, nose, and the other side of the throat. The main role of the pharynx, in the process of breathing, is to receive air from the nose and mouth and warm it to body temperature prior to its entry into the respiratory system. Larynx is an organ located in the center line of the front of the neck, which is used for breathing, voice formation and protection of the respiratory system during ingestion. It is built of muscle, cartilage and connective tissue. Three of the anatomical larynx: Coil (lat. Glottis), the space above the vocal cords (lat. Supraglottis), and the space below the coil (lat. Glottis). A special role has the protection cover (lat. Epiglottis), preventing the tip ends of the larynx and trachea still, e.g. prevent aspiration and possibly suffocation.

The trachea is a tube through which air flows in the bronchial tubes, the inner diameter 20 to 25 mm, and length 10-16 cm. It extends from the larynx to the primary bronchus, is made up of cartilage rings 15-20 C shaped securing the front and the side of the trachea. The lungs (pulmones) are the main body of the respiratory system. They are located within the thoracic cavity, and take her the most part. are protected by the ribs. Comprise the make (lat. Pulmo sinister) and right (lat. Pulmo dexter) lung. Left lung has two, right and three lobes (lat. Lobe) which are further divided into lobules (lat. Lobules). Outside the lungs are enveloped in a membrane called the pleura (pleura). The inner part of the membrane which covers the lungs, called the visceral pleura (pleura) and the external covering lining the chest is parietal pleura.

Lungs are placed against the lower part of diaphragm (diaphragm) - muscle baffle located between the thoracic and abdominal cavities. Bronchus or bronchi (lat. Bronchus) formed at the lower end of the trachea, which is divided into the left main bronchus, which leads to the left lung and the right main bronchus, which leads to the right lung. Each main bronchus enters the lung, where it continues to branch into lobar bronchi (secondary bronchi). The main left bronchus is divided into two lobar bronchi, and the right main bronchus in three lobar bronchi, each for a slice. Next, each lobar bronchus within its lobe divided into segmental bronchus (second lobe bronchus), which are further divided in the tertiary bronchus, bronchiole, from which the (lat. Bronchiole), and further the terminal bronchioles (lat. Bronchiole TERMINALES).

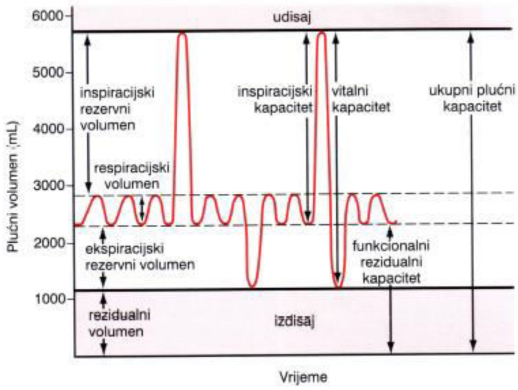
Bronchioles are different from the bronchus They do not contain cartilage and glands in their walls. Further branching bronchioles leads to ductal lines (lat. Ductule alveolares), whose walls consist of alveoli. The basic building block of the lung is the acinus, in which enters one terminal bronchioles which further branch into smaller segments with the alveoli. In the alveoli, the gas exchange takes place. Each lung lobules (lat. Lobules) consists of fifteen acini. The wall of the alveolar ducts and alveoli is built from flat cells (pneumocytes type 1 and type 2) through which gas exchange takes place. Withim the single alveoli are capillaries and pulmonary circulation leading carbon dioxide that is released, and the oxygen inhaled, to other organs. Normally, about 97% oxygen from the lungs to the tissue transmitted chemically is combined with hemoglobin. The remaining 3% of oxygen dissolved in water is transferred plasma and blood cells. (M. Boskovic 1964).

Pulmonary ventilation and capacity

To further understand the behavior of the human body of the apnea, and particularly for understanding the relationship of oxygen and carbon dioxide, pulmonary ventilation should be clarified. The aim of this chapter is to explain in more detail the terms of lung volume and lung capacity. The gases within the lungs behave differently at sea level and at certain depths. For easier understanding of all processes that take place in this section is worked out a process of movement of the molecules within the body, partial pressures affecting the regular pulmonary ventilation and gas laws can explain that the human body is exposed to a certain depth when diving in apnea.

Pulmonary ventilation can be studied by recording the volume of air entering the lungs or from the method comes spirometry. A spirometer consists of a drum, which is immersed in a container with water and a balanced weight. In the drum of the gas mixture for inhalation, typically air or oxygen, and a tube that connects the chamber with the mouth. During inhalation and exhalation drum is raised and lowered, and to kymograph the recorded curve of these movements. Shows change in spirometry lung volume in different embodiments of breathing. To help show pulmonary ventilation, the air in the lungs is divided on the diagram in four different volumes and four kinds of apacity. When you add them up, give the maximum volume to which the lungs can stretch. Meaning of each volume can be defined like this: tidal volume is the volume of air inhaled and exhaled in any normal respiration and male adults is about 500 ml. Inspirational reserve volume is maximum extra volume of air that can be inhaled after a normal respiratory volume when the subject inhales strongest and typically is about 3000 ml.

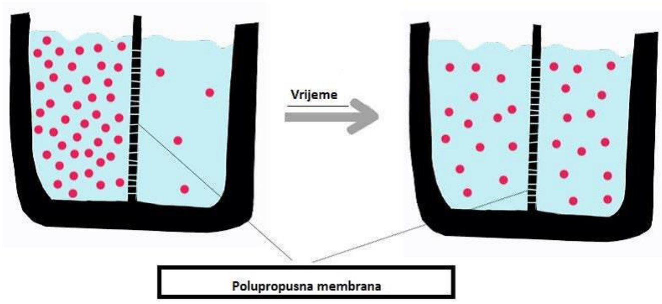
Expiratory reserve volume is the maximum amount of additional air which, after normal exhalation by forcing exhaled breath can be, but normally is about 1100 ml. Residual volume is the amount of air remaining in the lungs even after the strongest exhalation. The average volume is about 1200 ml. When describing events in the pulmonary cycle is sometimes desirable to consider together two or more of said volumes. Such combinations are referred to as lung capacity. Inspiratory capacity equals to the sum of the respiratory volume and inspiratory reserve volume. This is the amount of air (about 3500 mL) that a person can breathe in, starting from the level of normal expiration and stretching to the full lung size. Functional residual capacity is the sum of expiratory reserve volume and residual volume. This is the quantity of air remains in the lungs after normal expiration (about 2300 mL). Vital capacity is the sum of inspiratory reserve volume, expiratory respiratory volume and the reserve volume. This is the maximum amount of air that a person can force from the lungs, and at first inhales maximally and then exhales maximally (about 4600 mL). The total lung capacity is the maximum volume to which the lungs can be stretched best effort (about 5800 ml), and equals the sum of the vital capacity and the residual volume. All of lung volumes and capacities in women are less than men in the 20 to 25% and higher in those with an athletic built, than in low, asthenic person (Guyton & Hall, 2012).



Picture 3. Representation of lung volumes and capacities (Guyton & Hall, 2012).

After the alveoli ventilated with fresh air, the respiration process is followed by an oxygen diffusion in the lung alveoli from the blood and carbon dioxide diffusion into the opposite direction, from the pulmonary blood into the alveoli. All gases which are discussed in the physiology of breathing simple molecules move freely among one another, and this process is called diffusion. This is as true for gases dissolved in fluids and tissues of the body. For the diffusion of the required energy source, and that is the kinetic motion of the molecules themselves. Except above absolute zero, in all the molecules of all substances is constantly moving. If the chamber in a gas or in a solution in one side of the gas concentrations of the large and small on the other, the net diffusion of gas will occur from areas of high concentration to the area of lower concentration. The cause of this happening is evident; there are many more molecules in left field that diffuses toward right field, but molecules that diffuse in the opposite direction.

The pressure applied to a surface formed from the continuous striking of the surface molecules that are moving. Therefore, the gas pressure acting on the surface of the airways and alveoli is proportional to the overall average force applied all molecules of that gas in the given time hitting the surface. This means that the pressure is directly proportional to the concentration of gas molecules. In the physiology of breathing it is a gas mixture consisting of oxygen, nitrogen and carbon dioxide and at least in part of a noble gas and water vapor. Size diffusion of each of the gases is proportional to the administrative pressure that creates the gas and called its partial pressure (Guyton & Hall, 2012).



Picture 4. Representation of diffusion

What you should know about pressures

The term partial pressure can be clarified as follows. Take the example of air, consisting of 79% nitrogen and 21% oxygen. The total pressure of this mixture at sea level amounts to 101.3 kPa. From the previous description of the molecular basis of the pressure it is clear that each gas contributes to the overall pressure in proportion to its concentration. Thus, 79% of 101.3 kPa derived from nitrogen (80 kPa), and 21% of oxygen (about 21.3 kPa). Therefore, the partial pressure of nitrogen in the mixture was about 80 kPa, and the oxygen partial pressure of 21.3 kPa. The total pressure is 101.3 kPa, which is the sum of the individual partial pressures (According to Guyton & Hall, 2012).

The partial pressure of each gas in the alveolar gas mixture of respiration seeks to suppress that gas molecules in solution into the blood-alveolar capillaries. In contrast, the molecules of the same gas that are already dissolved in the blood randomly moving in the fluid in the blood, and some of these molecules back into the alveoli. Size restoring administrative molecule is proportional to its partial pressure in the blood. Net-diffusion depends on the difference between two partial pressures. If the partial pressure of free gas within the alveoli higher, which normally applies to oxygen, then more molecules diffuses into the blood than in the opposite direction. Conversely, if the partial pressure of the dissolved gas in the higher levels, which normally applies to the carbon dioxide, occurs the net diffusion of the alveoli.

The concentration of gases in the alveolar air is not in any case equal to the concentration in the atmospheric air, which can easily be seen by comparing the composition of the alveolar air with a composition of atmospheric air. This difference is due to several reasons. First, with each breath the alveolar air is only partially replaces the atmosphere. Secondly, from the alveolar air oxygen is continuously absorbed into the pulmonary blood. Third, carbon dioxide continuously diffuses from the pulmonary blood into the alveoli. And fourth, dry atmospheric air entering the airways and is moistened before it reaches the alveoli. Oxygen is continuously absorbed from the alveoli and blood of pulmonary capillaries and alveoli in inhalation constantly entering new oxygen from the atmosphere. As quickly absorbed oxygen, its concentration in the alveoli becomes smaller. Conversely, the faster a new atmosphere of inhaled oxygen in the alveoli, its concentration becomes higher. Therefore, the concentration of oxygen in the alveoli, and therefore its partial pressure, determined the rate at which oxygen is absorbed into the blood and the speed with which new oxygen enters the pulmonary ventilation process.

Carbon dioxide is constantly produced in the body; the blood is transferred to the pulmonary alveoli and from there continuously removes ventilation. Alveolar pressure of carbon dioxide is increased directly proportional to the rate of excretion of carbon dioxide, while the alveolar pressure of carbon dioxide decreases inversely proportional to alveolar ventilation. Thus, the concentration and partial pressure of oxygen and carbon dioxide in the alveoli determine the intensity of absorption or excretion of these gases, and the size of the alveolar ventilation (Albano, G., 1963, Gosovic, S., 1990, Lozovina, V., 1991,).

Behavior and operation of media (water) in free dive conditions

All laws which are processed below explain the behavior of air, e.g. gas that makes the diving conditions in apnea. Hypoxia is the professional title for the lack of oxygen in the blood and tissues. It occurs due to reduced oxygen partial pressure in the inhaled air or oxygen being unable to be used in the body. The human body is adapted for life in air under pressure of about one bar, in which oxygen is present to 20.8%. This percentage corresponds to a partial pressure of 0.208 bar. If the observation limits this force per unit area of $1m^2$, we come to the concept of pressure. Therefore, the pressure is expressed by a unit called Pascal (Pa), and means Newton per square meter. In use are those and other units of measurement: bar (bar), normal atmosphere (atm), technical atmosphere (at) kilogram per square centimeter (kg / cm^2), millimeter of mercury (mmHg or Torr). It is known that the percentage refers gases in the air does not change in the atmosphere is not at high altitudes. However, general air pressure and partial pressures of gases in it are lawfully reduced. As the standard atmospheric pressure at sea level, taken from the pressure 1013 hPa = 1 atm, although the actual pressure varies depending on the location and weather conditions. The atmospheric pressure is reduced due to reduction of non-linear air density with increasing altitude. Liquid from solids differ in that they are poorly interconnected particles (cohesive), and is easy to run and oppositely while they may be of different density and gravity.

Due to its own weight, have internal hydrostatic liquid pressure, which is transmitted and applied to the outside of the body. Hydrostatic pressure is a result of the weight of the liquid; each particle is exposed to a pressure of all the other particles above it. According to the direction of action it can be divided into the pressure toward the bottom, hips and upward. A free diver stays and their activity was carried out in a medium of fresh or salt water.

Hydrostatic pressure is part of the environment for the diver. The hydrostatic pressure is the pressure of the water column above the diver's body. The pressure of the water column does not include the atmospheric pressure. Dive depth increases, the increasing weight of the water column, the pressure of which is exposed to the diver rises. This increase in pressure is linear, and can be calculated for each depth, if known density of water in which to dive. The Adriatic Sea has a density of 1026 kg / m³. To a certain depth h will determine the hydrostatic pressure, calculating the force acting on an area of 1 m². This force is determined by multiplying the weight of the column of water (the sea) of g, e.g. with a standard acceleration of gravity, according to the known formula F = mg. Water column weight can be obtained as the product of the column volume and density of the sea.

If we take into account that the volume of this column by an amount equal to his height, since it is the base of 1 m², the calculation looks like this: the pressure of the water column at a depth of 10 meters is 10 m³ x 1026 kg / m³ x 9, 81 m / s² = 1006 hPa; e., about 0.993 atm. At a depth of 20 meters this pressure is twice as big, and it can be concluded that the increase in depth of 10 meters, the pressure increases to about 1 atmosphere. Calculation of the atmosphere should be added to 1 atmospheric pressure, and to finally obtain the calculation which tells us that the depth of 10 meters operating hydrostatic pressure of about 2 atmospheres, at a depth of 20 meters hydrostatic pressure of 3 atmospheres, etc.

Robert Boyle, 1662, experimentally found that the gas pressure increases if it is compressed to a smaller volume. Therefore, the gas pressure is inversely proportional to its volume. Depth range and relative change in pressure 0m - 50% 5m, 5m - 10m 33%, 10m - 15m 25%, 15m - 20m 20%, 20m - 25m 17%, 25m - 30m 14%, 30m - 35m 12%, 35m- 40m 11%. This law determines the behavior of gases that are contained in the human body in various cavities, since it is during the dive exposed to frequent changes in pressure due to changes in depth. Guillaume Amontons, 1700, stated that no gas pressure is proportional to temperature: likewise it has empirically been known that the volume of gas is increased by heating. Proportionality of volume with temperature, with the foregoing principles, is transformed to the gas equation Joseph Louis Gay-Lussac: P. R = m T (where m is the molar volume of gas and the proportionality constant R. Law describes the simultaneous isothermal (T = constant) and the pressure change of gas volume. Mentioned equations are valid only in the strict sense of the 'ideal gas'', e.g., the gas in which the molecules do not occupy space even interact with some power. However, for the purpose and conditions of explaining the behavior of gases at snorkeling, are considered to be sufficiently precise.

Table 1. Representation of relative pressure change on every 5 m (http://www.submania.hr/index.php/ronjenje-na-dah/fiziologija-i-medicina/17-pregled-plinskih-zakona).

Depth range	Relative pressure change
0m – 5m	50%
5m – 10m	33%
10m – 15m	25%
15m – 20m	20%
20m – 25m	17%
25m – 30m	14%
30m – 35m	12%
35m– 40m	11%

Dalton's law is about the pressure of the gas mixture, which is essential for divers to breathe. Law applies particularly to the air, which is a mixture of oxygen, nitrogen, carbon dioxide, and other gases with a smaller ratio. Dalton's law states: '' The total pressure of the gas mixture equals the sum of the partial pressures of each gas ''. The partial pressure of a gas in the mixture equal to the pressure that would have the same amount of the gas that, if he would make the whole volume occupied. Expressed formula partial pressure of the gas X in the mixture is equal to the product of general pressure and percentage of this gas mixture divided by 100. Dalton's law is very important in diving because it determines the behavior of individual gases from the air mixture in the process of breathing.

Dalton's law does not describe fully the real gases. The differences are especially large at high pressures when the molecules are very close to each other, and come to the fore intermolecular force, and changing a pressure value. Henry's law says the solubility of gases in liquids. The dissolution of oxygen in the blood and release of carbon dioxide from the blood are a key part of the breathing process. Henry's Law states: '' at a constant temperature, the amount of a gas to be dissolved in the liquid is proportional to the pressure ''. If it is a mixture of gases, each gas in it is acting independently. Thus, the gas mixture will dissolve in a liquid, as long as each gas mixture which makes that it reaches the same pressure as there is in the gas mixture. The dissolution rate of a particular gas is proportional to the pressure difference of this gas in the liquid and beyond. This law is necessary good knowledge and understanding with snorkeling because it explains the alveolar gas exchange, which poses a threat to divers if not thoroughly familiar with it (Meter, J., 2007, Schagaty, E. Andersson, J., 2014.). The modern era of snorkeling began with Enzo Maiorca and Jacques Mayol, disproving the theory of the then medicine on depth limits for people. Since that time, medicine has made considerable progress in explaining the physiological phenomena that are important for snorkeling. Today, no equipment, partly or fully equipped (mask, snorkel, fins, isothermal suit, sonar, security buoy) dive million people. In apnea diving is done spontaneously usually from recreational initiative.

Apnea is always the first stage of training autonomous divers. In addition to recreational and sport competition application, snorkeling has safety significance. Security purposes are reflected in the self-rescue or rescue others in the water.

This technique, if you know the general and special procedures, may be more effective to save the defenseless people at risk of drowning, leaving the car sank, sinking ship or help people who are in them. This technique, in its somewhat modified form, is used for safe emergence for difficult diving in the absence of air or failure of the autonomous diving apparatus (Lozovina, 2001).

Although free diving is the most widespread and technically the simplest form of diving, it is from the physiological point of view the most complex and unknown. Despite the simplicity of diving in apnea, in general, and especially in some forms of competitive diving (diving to the maximum time, maximum depth or distance traveled) and certain work activities (fishing, photo safari), it is very dangerous. It sounds incredible and absurd that in free diving far often victims experienced and very well trained divers with long diving-serving. The reason is that they no longer hold your breath achieving the greatest depth and long retention under water. (Lozovina, 2001).

In practice, we will dive exclusively in inspirational apnea, which means that divers use the air retained in the lungs after a maximal inhalation. The duration and depth depend on many factors: age, gender, vital capacity, physical fitness, motivation, alertness, pressure and ambient temperature. In normal atmosphere, the duration of the apnea, the average man is from 30 to 60 seconds. In inspirational apnea, on average, men can hold their breath longer than women.

Apnea can be extended by hyperventilation, reinforced, deep and rapid breathing before holding the breath for 3-4 minutes. Apart from hyperventilation, apnea can be extended and inhaling pure oxygen at more than 24.03 minutes (the owner of the record is Aleix Segura), and the application of modern techniques of ventilation and relaxation at nearly 11.35 minutes (the owner of record Stephane Misfud). The average man diving on the breath to a depth of 3-4 meters, a trained breath-hold divers to depths of 25 meters in apnea, which takes about two minutes.

Changes in the functioning of the senses during apnea

During a dive in apnea occurs series of significant changes: The change in the functioning of the body's senses, changes in the values of pressure in closed cavities of the head, Changes in the heart and the condition of the vascular system, changes in the balance of body fluids, changes in the pressure gradient along the gastrointestinal tract, changes in body heat, changes in maintaining euglycemia, Changes in the scope and intensity of muscle activity, and the most important changes in lung volumes and lung capacities, and in the values of partial pressure in the lungs.

Man hears sound in two ways. Sound is vibrations in the atmospheric air (direct conductivity) beyond a speed of 300 m / s, and encourage vibration of the eardrum and cause resonance of skull bones (bone conductivity), and thus sound vibrations transmitted to the inner ear where stimulate the organ of hearing. Recognition direction (with an accuracy of 1 to 3 degrees) from where the sound is coming, based on the fact that the brain is able to detect extremely small, to 0.03 milliseconds, the difference in arrival time of sound in that ear which is further away from the sound source of the ear which is closer. In aqueous medium, air conductivity is impossible. In addition, sound vibrations are five times faster spread in water than in air, and the less absorbed than in the air. Consequently, the water sound vibrations almost simultaneously come to the organs of hearing in both ears; it is difficult to ascertain the position of a sound source. In short, sound in the water is heard better, but it is harder to determine the direction from which it comes.

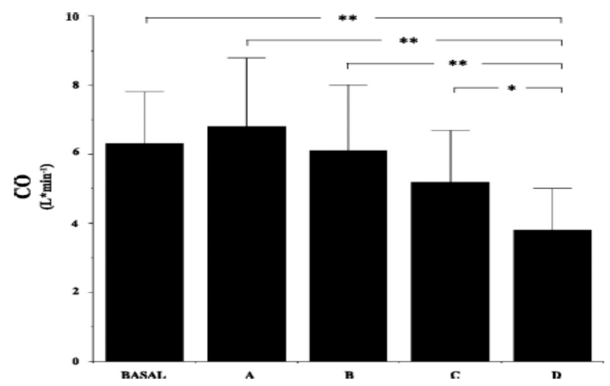
In the water, in the depth, visibility decreases. Visibility is reduced due to absorption of light (speed of absorption is proportional to the amount of dissolved or suspended particles), and thus the depth of 5 meters the intensity of sunlight is reduced to one fourth, and of 15 m in an eighth value of the surface. The absorption of light is not the same for all parts of the spectrum, so that the color red is losing already at 3 meters deep, orange to 5 meters deep, yellow at 10 meters, and the blue and green at 30 meters depth. Visual acuity is impaired because of the amount of dissolved particles and significantly less pronounced refraction. In order to improve the visual acuity of the water, between the eye and the water is placed flat glass mask with a refractive index of light beams 1,5, which at the same time isolated from water layer around the air. Mask acuity becomes satisfactory, but due to a stronger refraction of light rays, the objects in the water appear closer to a quarter and increased by one-third.
In the middle ear and sinuses during descent creates a vacuum that needs to be equalized or reversed. Otherwise you may damage the lining of walls of these cavities, which are more pronounced the higher downforce, and that exposure lasts longer.

Because of high blood pressure, the thorax decreases, so its volume decreases (and so do lung volumes), which promotes the inclusion of a protective mechanism, the centralization of blood flow. Hydrostatic pressure water density and mechanically displace blood from the abdomen and lower extremities, and the cold water improves compression of peripheral blood vessels, reducing blood flow to the limbs, and thus contributes to centralization of the blood. The chest cavity and thus can arrive over a liter of blood, which fill the space created by reducing the volume of the lungs. Thus significantly reduce the possibility of crushing the thorax and organs that it contains as the incompressible blood and any other liquid.

This mechanism of redistribution of blood, circulatory centralization, contributes to facilitating dives that are deeper than dives that can be calculated knowing the value of residual volume to surface. Centralization of circulation increased inflow of blood to the heart, allowing 30% higher cardiac output while reducing the heart rate - bradycardia mediated stimulation of the vagus nerve. The role of vagal is very important because the center of the regulation of the heart transmits data collected: Thermoreceptors in skin which increase the price of immersion in cold water, the baroreceptors of the skin which increases the price of increased hydrostatic pressure exerted thereon during the immersion, baroreceptor lung are stimulated by change in volume of the lungs due to the change lung volume due to size changes of the thorax due to elevated hydrostatic pressure.

The increase in blood volume in the thoracic cavity increases the pressure in the left atrium volume which stimulates receptors in its wall with a consequent reduction in the secretion of anti-diuretic hormone (ADH), resulting in immersion diuresis (urination).Thus the usual urine output can increase up to five times, which may lead to dehydration with consequent hypovolemia (decreased blood volume in the circulation which occurs due to the stronger bleeding or because of strong dehydration) and hypotension (means low blood pressure) or to hypothermia (decrease in body temperature at less than 35 ° C) as one liter of urine output decreases the body temperature of 0,5 ° C. Sweating caused by increased muscular exertion, and immersion diuresis wear body fluid for wetting of the inhaled air, to release of the hypovolemia and hypotension, tachycardia originating and thus increasing the oxygen consumption. (Guyton, A. C .; Hall, J. E, 2012).

Number of heartbeats per minute lower than 60 is defined as bradycardia and represents a deceleration of heart action. Recent research has shown that when people during a short breath-holding during a dive to a depth of 10 meters occurs hemodynamic pattern qualitatively similar as in marine mammals. One such study (Marabotti et al. 2009 according to D. basks 2015) using Doppler echocardiography (heart ultrasound) tested the cardiovascular response of subjects in various stages of immersion of the whole body in the water gradually increasing the ambient pressure by diving into the depths. Phase measurements of subjects were: basic phase of the water - A submerged body with the head out of the water - B, and the head body with the immersion snorkel crust on the surface, C-head and body immersed in the water on the surface of the apnea, D - Diving apnea at a depth of 5 meters. All the time measured by heart rate, left ventricular volume and cardiac output. Data analysis revealed a significant reduction in the left ventricle (systolic and diastolic), cardiac output and heart rate. Especially the cardiac output was lower stage diving at a depth of 5 m (D) than in the other phases of research.



Picture 5. Representation of minute heart volume in different phases of dive (Baksa, 2015).

It seems that immersion of the body in the water and breath holding only contributes to marginal cardiological changes, but the increase in hydrostatic pressure shows highly responsible for such chemodynamic changes (D. 2015 Bucks).

An increased hydrostatic pressure, into the abdominal wall and the abdominal cavity moves the contents of the chest cavity. By changing the position of the body by the action of hydrostatic pressure, changes the pressure gradient along the intestinal tract, so that the pressure gradient between the stomach and esophagus, that the surface is about 6 mm Hg can be doubled after the dive. This can lead to the return of gastric contents into the esophagus, and is manifested heartburn or vomiting.

Reinforced muscle contraction produces a significant amount of heat, which drains water from the body 20 times faster than the air generates considerable heat. Then wear body heat to the heating of the inhaled air, and the decrease in blood flow due to centralization of blood flow of the limbs, and immersion diuresis, to release of the hypothermia. The body then creates heat from muscular exertion, tremors, which requires a very large amount of energy provided by the available glucose. Apart from hypothermia, it can lead to overheating.

Sudden immersion of an overheated body, for example. After being in the sun in the neoprene suit for a prolonged period, it can result in hydrocution - water shock.

The supply body energy during snorkelling is necessary for markedly enhanced brain and muscular work, especially during dives at greater depths. So when surfacing with greater depth should exceed a significant distance with overcoming resistance to movement through the water, which provide the gravitational force, the viscosity of water and the weight of the water column. Increased consumption of glucose with inadequate compensation can lead to hypoglycaemia. Signs of hypoglycemia include feeling of physical weakness, mental confusion and distraction, irritability and numbness to the stimuli of the environment. Severe and prolonged hypoglycemia can lead to death.

Increased intensity of muscular work is also a feature of diving in apnea. Proper ventilation of the preparation of apnea involves intensive operation of the main (diaphragm) and auxiliary (intercostal, jugular, subclavian) of the respiratory muscles, and overcoming the increased dead space in the functional snorkel. Work fins involve intensive use of powerful and large thigh muscles, with consequent production of heat and sweating. Due to the increased venous inflow, caused by the centralization of blood flow, enhanced and work muscles that always work tirelessly and never stop the heart.

In the study of virtual reality in kinesiology (no. 0034216 Institute of Technology), designed simulator for a competitive discipline in free diving, where all measurements are performed in the virtual rather than real submarine, without the risk of death for patients. Computer with appropriate software, VR generates the underwater world, in which the subject can be subjected to different requirements. In order to experience immersion respondents was as close to the real experience of diving, the simulation involved a mechanical pulley with anchor rope, whose pulling respondent receives tactile feel close to that on the way up to the surface. Diving depth and speed promotion code depth, the diver follows that the HMD helmet, are in line with the reality. As part of the experiment, a sample of 70 students of the Faculty of Kinesiology in Zagreb was measured.

Measurements of the variables: (1) Static apnea - maximum duration of breath holding under water in the pool. (2) Variable weight - simulation competition discipline diving in depth on the breath. Subjects were divided into two functional categories based on the measurement results (successful - less successful) that actually describe the categories beginners / amateurs and licensed sport divers / professionals). It was determined by which of the categories of "blends" in the virtual offshore. Established the normality of the distribution of the results of examinees in the group of people who have not experienced 'drowning' and poorly identified and bipolar distribution in the group of those who are experienced 'drowning' '. Results' drowned '' subjects were divided into two groups: those with poorer results and those with good results in the measured variables. The measurement procedure includes a detection risk criteria divers. Each participant who is on the simulator "drowned" more than twice in four attempts dives declared a potentially risky diver.

There have been cases of 4/70. Occurrence of blackouts (3/70) simulator that had happened only subjects with extremely good results in the pool e.g. People with experience in diving. Among subjects who achieved average results there were no incidents. The study authors concluded that reasons 'drowning' of the respondents who have made good and those who have achieved poor results are obviously different. A group of underperformers ''drowns'' due to inexperience and poor assessment of personal skills. The group with excellent results "drowns" because of overrated capabilities. People with experience in diving activities tested the limits of their abilities and that go beyond their capabilities. The harmless laboratory measurements knowingly exposed to the risk is to believe that the real undersea often can enter the incident situation. Trained and good divers in apnea are usually killed just because training high lift boundary psychological barriers dangerously approaches the limits of their own abilities. There are psychological profiles disqualify candidates for divers. Some of the possible causes of diving incidents psychological state Vranjković-Petri, Petri, Tomic (2002): These are the people with claustrophobia, suicidal ideas, psychosis, in significant anxiety, severe depression, manic states, alcoholism, people taking drugs and preparations changing mood and people with inadequate motivation for diving. (I Drviš, D. Physical & Viskić-Štalec N., N. Grčić Zubčević-2006)

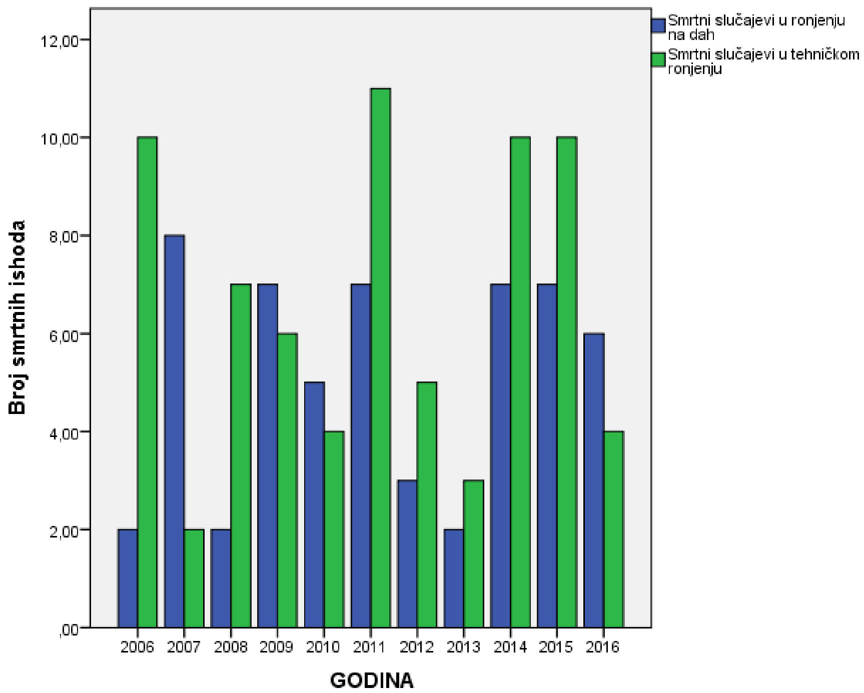
The most significant changes in the body during the dive in apnea is a steady decline in oxygen partial pressure with an increase in the partial pressure of carbon dioxide. Alveolar air gases in various stages of descent are followed by a variety of volume oscillations of the entire gas mixture. During the dive reduces their volume, increases density and partial pressures and, conversely, at the time of emergence will fall to them general and partial pressures and increase the volume.

After entering the maximum amount of air and then the dive, the oxygen consumption of the metabolic processes and muscle contraction, partial pressure of oxygen in all tissues will decrease and the carbon dioxide is increased. Since the body have receptors exclusively for the partial pressure of carbon dioxide, when the value of the carbon dioxide rises to the level of 6.2 kPa mentioned receptors will the central nervous system - the brain - send a warning signal, which a free diver will see as "air hunger" or the need for breath. This sensation should be taken seriously and immediately begin to surface.

Simultaneously with the increase of the partial pressure of carbon dioxide, the oxygen partial pressure decreases. As man has receptors to register the oxygen partial pressure decreasing, free divers actually have indirect information that the oxygen is near the critical limit. If free divers ignore signal for inhalation purposes, this ignored apnea extends supple, carbon dioxide continues to rise, and oxygen fall. When the partial pressure of oxygen falls below 5.3 psi, which is equivalent to an amount of 5% oxygen at atmospheric pressure, there will be unexpected blackouts, spontaneous automatic block of the epiglottis, and may or may not reach the heart block. Then free diver is in the stage threatening drowning, especially when he dives. In a variation when it comes to passing out, the epiglottis is blocked and heart failure in the lungs will not penetrate water and we will have a chance of pale drowning. If we have such a drowning man when rescue access in time up to 4 minutes from the moment of the incident after he was pulled to the surface, with a strong blow to the area of the heart it is possible to activate the heart and unblock the epiglottis. If this happens to a drowning man who is still unconscious on land, and if breathing and has a pulse call the paramedics. The second scenario is a scenario of blue drowning. This is a drowning man who fell into unconsciousness unannounced with blocked epiglottis but his heart continued to work. In these conditions the heart through the vascular system of oxygen from the blood is sent in all tissues that acute work, now in slow metabolism because muscles do not perform any work in the unconscious. In these conditions the oxygen partial pressure still falls and carbon dioxide increases. When the partial pressure of carbon dioxide rises to twice the value of those to whom he gave the first signal needs to breath and it is about 12 psi will yield a second signal to be inhaled. This will unblock the glottis and during attempted breathing lungs will fill with water. Such a drowning man is usually a blue color. When such a drowning person out of the water followed by an attempt resuscitation classical methods of artificial respiration and cardiac massage and the time when the establishment of autonomic function respiratory and pulse or until signs of certain death. (In. Lozovina 2001).

Table 2. Death toll in snorkelling and technical diving in the period 2006 - 2016.

				Deaths in snorkelling	Deaths in technical diving
YEAR	2006	1		2,00	10,00
		Total	Sum	2,00	10,00
	2007	1		8,00	2,00
		Total	Sum	8,00	2,00
	2008	1		2,00	7,00
		Total	Sum	2,00	7,00
	2009	1		7,00	6,00
		Total	Sum	7,00	6,00
	2010	1		5,00	4,00
		Total	Sum	5,00	4,00
	2011	1		7,00	11,00
		Total	Sum	7,00	11,00
	2012	1		3,00	5,00
		Total	Sum	3,00	5,00
	2013	1		2,00	3,00
		Total	Sum	2,00	3,00
	2014	1		7,00	10,00
		Total	Sum	7,00	10,00
	2015	1		7,00	10,00
		Total	Sum	7,00	10,00
	2016	1		6,00	4,00
		Total	Sum	6,00	4,00
	Total	Sum		56,00	72,00



Picture 6. Graphical representation of deaths in snorkelling and technical diving in the period 2006. - 2016.

Previous content, which thoroughly processed physiology of apnea, arose from the need to be interested in this activity, as potential divers to breath, thoroughly acquainted with the theoretical aspects of this discipline. How the diving complex and dangerous activity is evident from the data reported in Table 2 and in Figure 6. Data are presented as obtained from official sources, Croatian police services and search and rescue of the Ministry of Transport infrastructure Croatian Republic. Compared was the number of deaths in diving with technical diving with compressed air followed by the period of 2006 to 2016 years. In the mentioned period 56 divers were killed. In technical diving the death toll is 72. The annual mortality in apnea diver is 5.6 and 7.2 in technical diving diver. An interesting fact is that all the dead divers' death occurred in sport fishing and only one fatal case happened in the official sports competition. The sport fishing casualties have dived alone, therefore without the possibility of them at the beginning of the incident second diver ("pair") out of the incident situation and rescue of drowning. This aspect of diving safety paired unusual is important and should be the rule for both divers with small and for those with extensive experience in sport fishing. In sports and competitive diving, in all events, there is insurance in case of falling into the incident, the situation in competitions number suffering fatal minimal.

Conclusion

There is no safe diving in apnea in any diving activities (recreation and entertainment, sports and competitive, professional and activities of military divers, without thorough and good knowledge of the theoretical foundations. In recent times synergy of medical and technical achievements diving activity has developed into a complex and respectable activity and established itself according to professional and recreational diving.

Snorkelling, either as a sport, recreational or professional, is an extremely demanding activity with required knowledge and skills such as extraordinary physical and mental readiness, but also a thorough theoretical knowledge necessary to engage in this activity. The compelling and continuous appropriate health surveillance conducted specialized institutions in occupational medicine, sports medicine and Baroque. Training divers should attend institutions and organizations licensed for their training. As the training of divers is a very complex job in this paper, we have only to segment anatomy and physiology in the function of theoretical explanations of complex or dangerous activity if it is not addressed systematically and comprehensively. Everything stated in this paper is directly a function of security in diving in the sense of preventing diving danger.

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FIZIOLOGIJA APNEJE S NAGLASKOM NA DINAMIKU O_2 I CO_2 U ORGANIZMU I SIGURNOST ZARONA

Sažetak

Ronjenje na dah (apneja) jedina je čista anaerobna aktivnost koju čovjek upražnjava. Prilikom zarona na dispoziciji mu ostaje količina zraka, pa iz njega kisika, koju u trenutku zadnjeg udaha pred zaron ima u plućima, krvotoku i tkivima. Prilikom zarona kisik iskorištava za metaboličke procese i dodatni mišićni rad a njegov parcijalni pritisak stalno pada dok istodobno dolazi do porasta parcijalnog pritiska ugljičnog dioksida. Prilikom zarona u tekućem mediju (vodi), pod djelovanje hidrostatičkih tlakova, apnejaš se nalazi u stalnom stanju hipoksije a plinovi u organizmu apnejaša, pod tlakom, odnosno svojim parcijalnim tlakovima slijedeći određene zakonitosti ponašanja plinova pod tlakom, reguliraju vrijeme trajanja apneje a time i sigurnost zarona. Cilj ovog radajest pobliže upoznavanje sa svim činjenicama o fiziološkim procesima koji se tijekom zarona odvijaju u organskim sustavima apnejaša kao bi se omogućilo sigurno ronjenje i izbjegle incidentne situacija, što je omogućila sinergija medicinskih i tehničkih znanosti u objašnjenju ove složene i opasne ljudske aktivnosti.

Ključne riječi: *apneja, dišni sustav, parcijalni tlak kisika, parcijalni tlak ugljičnog dioksida, dinamika plinova.*

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