PULMONARY BAROTRAUMA IN DIVERS VS PROCEDURES INITIATED BY EMERGENCY MEDICAL PERSONEL

Martyna Krukowska, Katarzyna Jańczuk, Anna Ślifirczyk, Marta Kowalenko

Pope John Paul II Higher School of Education in Biała Podlaska, Medical Rescue Institute

ABSTRACT

Introduction: Pulmonary barotrauma consists in the damage of pulmonary tissues resulting from pressure differences in the body and the surroundings. Barotrauma may occur during diver's ascent with a held breath.
Objective: Presentation of symptoms in divers performing dives at shallow depths. A detailed description of pulmonary barotrauma as a direct hazard to life. Rescue procedure in the case of an occurrence of pulmonary barotrauma, methods of prevention.
Abridged description of the state of knowledge: Proper equipment preparation, systematic diving training, as well as systematic medical control aimed at conducting medical examinations with regard to staying under water, all constitute primary preventive measures. At the moment of an occurrence of pulmonary barotrauma in a diver it is necessary to perform first aid activities by qualified medical personnel and arrange for a quick transportation to the nearest hyperbaric centre.
Summary: Commonly, pulmonary barotrauma concerns individuals diving at depths up to 10 metres. Pulmonary barotrauma is a state of danger to one's health and life. Proper procedures at the scene of an accident as well as quick transportation to a hyperbaric chamber increase the chance of one's recovery and may constitute the necessary condition during rescue activities.
Keywords: pulmonary barotrauma, medical rescuer, arterial gas embolism (AGE), hyperbaric treatment.

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INTRODUCTION

Recreational diving develops along with the technical progress and utilisation of safe diving equipment.

The word "barotrauma" is derived from Greek, where: "baro" stands for pressure. Barotrauma may occur due to pressure differences inside air spaces in a diver's organism and the ambient environment, i.e. water. The reason for the failure to balance the pressure may consist in the following: the ascending technique, problems with diving equipment, panic, bravado, acquired or congenital areas of impaired ventilation, infection, diseases of upper respiratory tract, presence of a foreign body, polyps in the nose or paranasal sinuses, nasal septum curvature, stomach contraction and other.

The objective of the work is to present the symptomatology of health disorders in individuals diving at shallow depths and the procedures initiated by medical personnel. The authors provide a detailed description of pulmonary barotrauma, which may lead to a direct endangerment of one's health and life.

PULMONARY BAROTRAUMA

The first case of pulmonary barotrauma was noted in 1843 during underwater works conducted at the "Royal George" wreck [1].

The factors conducive to an occurrence of pulmonary barotrauma predispose the following conditions: asthma, past idiopathic pneumothorax, cysts, sarcoidosis, pleural adhesions, fibrosis of pulmonary tissue, acute and chronic infections, and other pulmonary diseases and traumas. However, the most common cause of the trauma consists in a held breath during ascent due to various reasons, e.g. air exhaustion in the diving cylinder, rebreather failure, loss of a ballast belt, diver being rapidly brought to the surface, larynx contraction due to panic under water, or uncontrolled and too rapid an ascent. Moreover, the reason can be the diver's bravado, ignorance, forgetting or, in unexperienced divers, lack of primary skills [2].

PULMONARY BAROTRAUMA PATHO-MECHANISM

The difference of pressures around the diver and inside his/her lungs after reaching the value of 60-80 cm H_2O causes damage to pulmonary parenchyma, which is too delicate, and as a result leads to lesions in the walls of pulmonary alveoli. Such a phenomenon is observable when a diver is tossed to the surface even from a small depth. Literature describes cases of pulmonary barotrauma at the ascent from the depth of 1.1 m.

Time of diving does not play a significant role in an occurrence of barotrauma, whereas the depths are usually rather small, up to 10 m [3].

The incidence of pulmonary barotrauma depends on the depth and pulmonary capacity. If upon drawing the air from the diving apparatus the diver will hold the breath close to his/her total pulmonary capacity, the ascent from one metre is already dangerous, as it may lead to an occurrence of barotrauma. Rupture of the wall of a pulmonary alveolus is accompanied by rupture of the surrounding blood vessels.

The damaged pulmonary alveoli are flooded by extravasated blood causing them to be no longer capable of performing their function and leading to atelectasis. Healthy pulmonary alveoli are pressed by the damaged ones and the blood found in intralveolar spaces. At the same time the pressure in the lungs increases, the alveolar air reaches capillary vessels in the blood, and as a result of circulation enters the left ventricle. Next, the blood rich in air bubbles reaches cerebral vessels through the aorta, rarer the coronary vessels, thus creating arterial gas emboli (AGE)[4].

In the case of damage to the alveoli located in the pleural area there exists a possibility of damaging the pleura. The air that gets there will cause pneumothorax. Whereas in a situation when pulmonary alveoli are situated close to the main bronchi, the air moving along them will filter through the mediastinum thus causing pneumomediastium. Further travel of the air upwards the chest and neck will lead to subcutaneous emphysema in this part of the body [2;5;6].

Symptoms and complications

Pulmonary barotrauma may take various courses, however in the majority of cases the symptoms occur up to half an hour following diving completion, although it may also happen that initially a symptomless period will take place followed by loss of consciousness and rapid death. Quite often the loss of consciousness occurs already in water.

In the event of rupture of the pulmonary parenchyma, and multiplicity of damaged structures we can expect the following symptoms: cough, coughing up of blood-coloured sputum, hemoptysis, shallow breath, pain during breathing, dyspnea, as well as cyanosis. Vast damage of lung structures may lead to severe respiratory failure, and as a result to death [2].

In the situation of damage to pulmonary alveoli located in the proximity of the main bronchi, the air can cause pneumomediastium, which is often symptomless. Moreover, it also occasionally happens that the air travels to the abdominal cavity or pericardial sac, thus leading to cardiac disorders. Massive pneumomediastium exerts an intensive impact on the heart and large blood vessels, and in consequence is manifested as: pain in the chest, shortened breath, constriction in the sternum area, foreign-body sensation in the throat, pain while swallowing, hoarseness. The auscultation of the precordial area confirms crepitation or crackling noises [4].

The air moving upwards the chest creates subcutaneous emphysema characterised by: crepitation under pressure, neck distortion, asymmetry of the supraclavicular area.

Tearing of pulmonary alveoli may lead to the rupture of the pleura. In such a case we wiill observe an occurrence of pneumothorax and expect the lung to collapse.

Occasionally, the damaged lung will create a valve enabling air movement only in one direction, with each breath causing the emphysema to be completed with air. The mechanism of ventilation emphysema causes that the pressure inside the chest increases and the heart and large vessels are moved onto the healthy lung thus pressing it.

Such an emphysema requires immediate decompression, otherwise will lead to death. The symptoms include: short acute pain at the moment of rupture of the pleura, shortened and accelerated breath, chest asymmetry, strong and instantly increasing dyspnea and accelerated heartbeat. Percussion examination confirms a tympanitic sound, whereas auscultation of the lungs indicates absence of rales [3;6].

The most dramatic form of pulmonary barotrauma consists in arterial gas emboli (AGE). They are created at the moment of rupture of pulmonary alveoli, when the air is pumped into the circulatory system. Air bubbles commonly reach the heart or brain causing impairment in their functions by blocking blood vessels [4].

The result of arterial gas emboli are changes in systemic and cerebral circulation. It is accompanied by an increase in the arterial blood pressure, with the brain stem releasing vasopressin into the blood. The plethoric brain stem leads to inhibited autoregulation of perfusion and the blood volume increases. The epithelial cells of arteries are damaged by embolic air bubbles and kinin is released causing an increased permeability of blood vessels. The occurring numerous processes cause a rupture in the blood-brain barrier leading to the development of cerebral oedema.

The proper symptoms of arterial gas emboli are often preceded by a seizure or cardiopulmonary arrest due to the closure of large arterial vessels by air bubbles. Convulsions are the effect of hypoxia in the cerebral cortex or mechanical compression. Emboli in the hemispheres are indicated by hemiplegia, aphasia and unilateral blindness. Bilateral blindness, on the other hand, indicates emboli location in the rear cavity of the skull. Hypoxia of the brain stem manifests itself in cardiopulmonary arrest.

The symptoms of gas emboli in the brain include headache, loss of consciousness, convulsions, apathy, torpidity, confusion, numbness or tingles, paresis, muscle paralysis, impairment of hearing, speech and sight, motor coordination, paralysis of the respiratory and circulatory system, as well as death [4].

The symptoms related to gas emboli located in coronary vessels include pain in the chest radiating to the neck, mandible or the left limb, fast and barely detectable pulse, decrease in arterial blood pressure, arrhythmia, symptoms of cardiogenic shock, cardiac arrest.

Emboli may also be situated in other parts of the body, however in that case they do not pose an immediate threat to life. When located in the skin they are manifested in its marbled appearance with white and livid-reddish patches [2].

Below we present the list of factors predisposing a diver to an occurrence of acute pulmonary adenomatosis:
- using diving apparatus;
- rapid ascent;
- lack of exhalation during ascent (panic, absence of breathing mix, problems with equipment);
- cough and hemoptysis after ascent.

The gas used during diving is kept in a cylinder under high pressure. The task of the apparatus is to ensure variable adjustment of the pressure of the breathing mix, i.e. the closer to the surface the lower the pressure, the deeper the higher the pressure, however always the same as that occurring around the diver. Following this principle the pressure inside the lungs and outside the chest should be equal.

Should a diver perform an ascent without an exhalation or with incomplete exhalations a difference in the pressure inside the lungs and ambient pressure will occur. The pressure around the diver is lower than that in the lungs. Pressure difference will cause rupture of pulmonary alveoli. The occurring cough "tries" to clean the lungs of the shred alveoli (treating them as foreign bodies).

The consequence is blood appearing in the saliva. The secretion has an intense red colour and is foamy (the air from ruptured alveoli). In order to suspect pulmonary barotrauma the symptoms need to occur in the abovementioned order. Commonly, they occur immediately or within 30 minutes upon diving completion [7].

FIRST AID ACTIVITIES AND PROCEDURES INITIATED BY EMERGENCY MEDICAL TEAMS

In the case of an occurrence of pulmonary barotrauma symptoms it is required to call for an ambulance and arrange victim transportation to a decompression chamber, as initially mild symptoms may either naturally recede or rapidly escalate thus constituting a threat to life. Each time it is necessary to consider the possibility of appearance of gas emboli, which can be efficiently treated only in a decompression chamber [8].

In the collection of SAMPLE interview it is required to establish the following: S – sings/symptoms, A –allergies, M – medicines –, P – past medical history, L – lunch – , E –events preceding[9].

It is significant that ITLS examinations (International Trauma Life Support) are performed by medical rescuers. A quick trauma examination includes: Examination of the head and neck (large injuries to the face, bruises, swelling, penetrating wounds, subcutaneous emphysema, widening of jugular veins, trachea dislocation); Examination of the chest (asymmetry, bruises, penetrating wounds, paradoxal movements, instability, crepitation); Rales (present, symmetrical, if asymmetrical - perform percussion); Heart sounds; Abdomen (bruises, penetrating wounds/gastroschisis); Pelvis (sensitivity, instability, crepitation); Lower and upper extremities (swelling, distortion, instability, motor activity, sensation). Move the victim onto a stiff orthopaedic stretcher, examine the back and buttocks (penetrating wounds, distortions, swelling in the sacral area). If the situation is critical the patient should be moved into the ambulance for the purpose of completing basic examination [9].

Moreover, it is necessary to perform examination of cranial and peripheral nerves allowing to confirm whether the patient: sees, hears, has symmetrical palpebral fissures, presents a squint, nystagmus, symmetrical pupils, difficulties in speaking, swallowing, presents facial movements, coordinated movements (finger-nose test), and also whether the patient is able to move the head, raise shoulders, move limbs, has preserved sensation.

Oxygen has a favourable effect in the occurrence of gas emboli, that is why its administration should be initiated as soon as possible. The optimal variant consists in providing it at the surface immediately after extracting the victim and continuation during the transport to the decompression chamber as well as during compression and decompression. The advantages of utilising oxygen therapy include: improvement in the oxygenation of damaged tissues; increased gas excretion from the organism, e.g. air; reduction of the size of previously formed bubbles; prevention of venous emboli [7].

The presence of gas emboli results in an increase in the permeability of blood vessels due to which water and plasma escape outside the vessels thus reducing the blood volume. An increase in blood density leads to disturbances in microcirculation, hence it is necessary to administer fluids. The objective of such treatment is restoration of proper volume of blood plasma, improvement of the blood flow in tissues, avoidance of hypotension, prevention of coglutination of blood cells. For this purpose the patients receive a slow transfusion of 500 ml Dextran, 1000 ml 0.9% NaCl or multielectrolyte fluid PWE. It is required to control the quantity of administered fluids in order not to overburden the circulatory system and induce pulmonary and cerebral oedema.

Administration of tranquillizers: 1-2 mg Relanium in doses fractioned to 10 mg i.v. causes: sedation of the patient, recession of convulsions, reduction of sensitivity to hyperbaric oxygen, reduction of vertigo, vomiting and nausea.

Administration of antitussive medicines – Codeinum hydrochloricum, Thiocodin or Droperidol (injection) causes absence of the coughing reflex and thus reduction of the tissue damage area, particularly the pulmonary tissue, which has an effect on a reduced number of gas emboli.

Administration of Lignocainum hydrochloricum, i.e. a local anaesthetic and an antiarrhythmic drug. The pharmacological activity of this medicine consists in an inhibition of stimuli formation and conduction in nerve fibres and in the cardiac conduction system. The drug has the capability of blocking sodium channels on the surface of nerve cells. Upon intravenous administration, it prevents the increase of intracranial pressure. It is administrated through a drip infusion in the dose ranging between 200 and 500 mg (not more than 3-4 mg/kg body mass).

The administration of 20-40 mg Furosemide due to cerebral oedema caused by gas emboli. Furosemide is a preparation belonging to loop diuretics (with anchor points within the nephron loop). It intensifies excretion of sodium cations (Na^+) through the inhibition of reversed sodium chloride resorption mainly in the limb of the nephron loop. Besides sodium ions, furosemide increases excretion of the ions of: calcium, magnesium, potassium, chloride and phosphate. Moreover, though the reduction in the blood volume it reduced arterial pressure. At the same time it weakens the reaction of the vessels located in smooth muscles to contraction evoking stimuli [10].

If necessary, it is required to initiate resuscitation. According to the guidelines of European Resuscitation Council of 2010, the ratio of compressions to inhalations amounts with regard to an adult person is defined as 30 compressions and two inhalations with synchronous massage. We begin with restoring patency of the respiratory tract, and if it fails proceed to perform chest compressions [11].

Pulmonary barotrauma most commonly occurs during diving with a breathing apparatus. Quite often, the person calling for help, a fellow diver, knows that medical recompression constitutes ultimate treatment.

Transport of a patient with pulmonary barotrauma should be as quick as possible, it is advisable to use a helicopter.

During transport it is necessary to control breathing and circulation, secure patency of the respiratory tract, perform oxygen therapy with 100% oxygen. The patient should be placed in a horizontal position on the left side, it is required not to administer anything orally, any analgesics, with the indication to perform fluid transfusion in order to prevent dehydration and shock. It is advisable to deliver diving equipment of the affected diver as well [11].

In pulmonary barotrauma gas bubbles get into the vascular system through previously damaged blood vessels. Gas emboli usually give cerebral and cardiac symptoms. The treatment of gas emboli is based on medical decompression supported with pharmacological treatment. Each of the elements of treatment of gas emboli has a significant impact on the efficiency, prognosis and possibility of occurrence of permanent damage.

Medical recompression is the quickest way to remove gas bubbles through: definite reduction of bubble size; their accelerated dissolution; improved tissue oxygenation; prevention of bubble growth during slow decompression.

The treatment of gas emboli is performed with the use of schemes available in the U.S. Navy decompression tables. The primary principle of their use consists in rapid compression to 6 atmospheres within the time of 1 minute, which allows instant bubble reduction to sizes preventing them from manifesting any symptoms. Rapid compression and an instant administration of oxygen significantly improve tissue oxygenation and reduction of emboli.

Two of the above factors enable restoration of ischaemic cerebral or cardiac functions. Treatment result depends on the time of emboli occurrence and the moment of treatment commencement in a decompression chamber. The sooner the recompression treatment is initiated, the higher its efficiency.

Patients with gas emboli, in whom treatment in a chamber was performed, manifest a significant neurological improvement. Hyperbaric oxygen treatment in the case of emboli located in the encephalon reduces or prevents intracellular oedema.

If a diver presents limited intensity or doubtful symptoms it is also necessary to implement treatment in a hyperbaric chamber, as a sudden occurrence of arterial emboli may constitute the cause of death. Recompression treatment of a healthy diver, on the other hand, does not bring any unfavourable results [12].

An occurrence of other results which do not require recompression should be treated by continuous administration of 100% oxygen to patients at each hospital.

PREVENTIVE MEDICINE

Pulmonary barotrauma may occur during very shallow dives. It is recommended to perform health classification among diving candidates. Any pulmonary pathology should be regarded as disqualifying. Diving is permitted after an approximately monthly period of convalescence following pneumonia or bronchitis; infections of upper airways or rhinitis also require a break in going under water until full recovery [2].

When staying under water the breathing should be even, calm, without deep inhalations, whereas during the ascent it is prohibited to hold the breath. The ascent must be performed at a slow pace so that the air in the lungs can even its value with the ambient pressure.

Diving equipment requires inspection prior to each dive, since even the best and the most expensive devices can fail. It is recommended to perform each dive with a spare "octopus" mouthpiece or an additional air source, e.g. in the diving vest.

In order to enhance diving safety, the principles of a partner system apply, i.e. diving in pairs [13]. Before entering water the partners should agree on their communication, define the emergency action plan, check the diving equipment: manometer indications, whether cylinder valve is open completely, if there are any other problems. After immersion, they control their behaviour maintaining a close distance to ensure mutual assistance.

The Regulation of the Minister of Sports as of 17 August 2006 on diving safety principles on the basis of Art. 53c Paragraph 4 of the Act of 18 January 1996 on physical culture (JL of 2001, No. 81, it. 889 as amended) defines the necessary conditions to be fulfilled before diving commencement.

They include in Paragraph 1, Subparagraph 1 the assessment of safety conditions in water, movements, depth, contamination and visibility in water; establishment of a plan for each dive; determination of communication techniques between divers and the principles of implementation of an emergency-evacuation procedure at the moment of hazard occurrence; as well as inspection of the equipment used during immersion. The equipment must be in a working order, meet specified norms and be properly suited to divers' skills and the planned diving profile.

Diving supervisor, i.e. usually a person with highest qualifications and the longest diving experience is obliged to: have a diving plan containing: procedure of safe entry and exit, rescue-evacuation procedures. Each dive needs to be secured with diving, medical, protective and communication equipment [14].

Pursuant to Paragraph 10 of the aforementioned regulation the organiser of a dive is obliged to supervise the implementation of safety principles and assure availability of the necessary medical equipment, i.e. first aid kit necessary for a particular diving profile ad oxygen kit enabling its administration at 15l/mi for the time of at least 20 minutes. It is important that the medical equipment is available at the place of diving, enabling its instant implementation.

Possible First-aid equipment:

-oxygen therapy kit,
-cylinder with oxygen,
-face mask to enable mouth-to-mouth ventilation,
-sterile needles,
-thermometer,
-scissors,
-tweezers,
-disposable gloves,
-dressings: sterilised gauze, bandage, triangular bandage, aseptic dressings,
-elastic bands, band-aids,
-aluminium foil - "life support foil",
-antipyretics, antiinflammatory drugs, anelgesics, anti-allergic drugs, anti cold, anti poisoning, relaxants, ear drops, antitussive drugs, peroxide.

It is crucial that the medicines and other products have a proper expiry date. Preventive medicine in diving is also connected with undergoing a diving course in order to obtain a diving licence but also skills ensuring a safe stay in and under water, with and without diving equipment. In Poland the most popular organisations conducting such trainings are KDP/CMAS and PADI. Diving is not a safe sport, thus it is required to adhere strictly to safety rules, as even one unfortunate incident under water may cost someone's life [2].

Irrespective of the diver training organisation, training system, instructor, diving place and weather the most important element consists in the effort put in the understanding of course contents and correct performance of exercises. Further diving practice will enable divers to master correct behaviours.

Summary

In order to increase diving safety it is required that divers are physically fit, have valid medical examinations. It is required to complete training and become familiar with and apply diving principles. Moreover, it is necessary to use certified diving equipment and perform equipment inspections before each dive. Diver's body contains numerous natural or artificially created air spaces that may be damaged if the pressure inside them is not levelled with the ambient pressure in water. There are plenty of methods of pressure levelling, and the ability of their use is the main condition ensuring diving safety and comfort.

When using a breathing apparatus it is required to breathe evenly and continuously. In emergency ascents it is required to exhale the air at all times. In the case of an occurrence of symptoms suggesting barotrauma or a different condition it is required to call for medical help.

It is indicated to administer oxygen immediately due to its favourable effect in the case of gas emboli. The optimal variant consists in providing it at the surface immediately after extracting the victim and continuation during the transport to the decompression chamber as well as during compression and decompression. The advantages of utilising oxygen therapy include: improvement in the oxygenation of damaged tissues; increased gas excretion from the organism, e.g. air; reduction of the size of previously formed bubbles; prevention of venous emboli.

Transport to a hyperbaric chamber should be as quick as possible, it is also advisable to use a helicopter. During transport it is required to control the patient's breathing and circulation, ensure airway patency, continuously administer 100% oxygen through a tight mask, the patient should be placed in a horizontal position on the left side, it is necessary to reduce oral administration, it is indicated to perform fluid transfusion to prevent dehydration and shock.

Medical recompression is the quickest way to remove gas bubbles through: definite reduction of bubble size; their accelerated dissolution; improved tissue oxygenation; prevention of bubble growth during slow decompression. The treatment of gas emboli is performed with the use of decompression tables, which ensures instant bubble reduction to such sizes that no symptoms are generated. Rapid compression and an instant administration of oxygen significantly improve tissue oxygenation and reduction of emboli. Treatment result depends on the time of emboli occurrence and the moment of treatment commencement in a decompression chamber. The sooner the recompression treatment is initiated, the higher its efficiency.

CONCLUSIONS

1. Pulmonary barotrauma is a state of threat to one's health and life.
2. Proper procedure at the scene of an accident and quick transport to a hyperbaric chamber give a chance of recovery.

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mgr Martyna Krukowska
Państwowa Szkoła Wyższa im. Papieża Jana Pawła II w Białej Podlaskiej,
Zakład Ratownictwa Medycznego
ul. Sidorska 95/97, 21-500 Biała Podlaska