SELECTED RISKS OF THE DECOMPRESSION PROCESS. PART I: SELECTED INHERENT RESIDUAL RISKS IN THE DECOMPRESSION PROCESS

Ryszard Kłos

Polish Naval Academy, Department of Underwater Work Technology in Gdynia, Poland

ABSTRACT

A safe transition from a higher-pressure atmosphere to a lower-pressure atmosphere is achieved by means of a planned decompression process, usually through changes in pressure and/or the composition of the breathing mix as a function of time. However, the decompression process is influenced by a greater number of inherent[1] factors than merely changes in pressure and composition of the breathing mixture, the values of which should be maintained within certain ranges. However, there are instances where control over them cannot be maintained, leaving elements of residual risk[2] to the decompression process. The safety of decompression should be assessed, inter alia, by analysing this risk for each implementation of the decompression process.
Keywords: decompression, decompression sickness, risk, hazard.

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INTRODUCTION

Every decompression system in use is subject to observation and assessment by users, and in some cases, also to diagnosis[3] by the monitoring bodies set up for this purpose. The analysis of the observations collected leads to the development of certain practices, which may begin to form part of the so-called 'good practices'. Although the conclusions of such collected observations usually refer to current theories, they cannot constitute precise rules of conduct, as they have not been verified in the scientific process and validated[4] Hence, those observations are reluctantly described in the form of recommendations[5], although they are important prerequisites for analysing the residual risk of decompression. If the conclusions do not yet constitute confirmed knowledge[6], they may be passed on to other users only within the training system.

DECOMPRESSION

Decompression consists in causing a controlled disturbance of the state of equilibrium leading to the formation of a gradient of partial pressures of gases between the breathing atmosphere and tissues. This gradient is the driving force behind the decompression process. The aim of such a procedure is to safely bring the body's gas balance to a state of equilibrium with the reference atmosphere which the decompression process is aiming at. The reference atmosphere, to which the decompression process leads, is usually the sea level. It can be the atmosphere surrounding a body of water elevated above sea level, where the pressure is reduced in relation to the normal pressure prevailing at sea level. It can also be the pressure in an aircraft, where the pressure is usually ¼ lower than normal, or in a helicopter[7], where the difference can be even greater. The reference atmosphere can be an underground cave or an underground corridor where the pressure can be much higher than the atmospheric one[8]. It may also be the habitat to which the diver returns after a trip from a saturation plateau.

The rate of decompression and the composition of the breathing mix is so selected that the partial pressure gradient guarantees a safe decompression process on the chosen path towards the reference atmosphere, but also that the process is as effective as possible. Decompression may also include decompression stops used to lower the current value of the partial pressure gradient before continuing towards the reference atmosphere.

To estimate the value of a controlled disruption of the equilibrium leading to a safe and effective partial pressure gradient of gases between the breathing atmosphere and the tissues, it is necessary to determine the initial saturation level. The initial state is estimated on the basis of the profile of the course of the dive immediately preceding the moment when the decompression process begins. Sometimes it is also necessary to take into account previous dives and their decompression profile. Most often it is defined roughly using a nomogram in the form of a table, which takes into account the maximum depth achieved during the dive and the interval between the start of the dive process and the start of decompression. The same thing is done as decompression progresses. It is tempting to make estimates for each, even the smallest change in depth, as permitted by an electronic decompression meter, which can be both its greatest advantage and its main drawback[9].

PREVENTION

Special decompression procedures are used to prevent the occurrence of DCS. Most often their descriptions are rather brief. It is required that the necessary knowledge for the proper use of the decompression system be acquired and tested during the obligatory courses and training undertaken at particular levels of a divers' career advancement.

There are exhaustive comments in the studies on decompression systems, but access to them is not universal. Rarely is the necessary knowledge provided in a comprehensive manner, as in the case of Bühlmann's decompression system [1]. At times, publications are produced that generalise the approach to decompression [2,3]. Knowledge conveyed during training courses is usually accompanied by some kind of printed course materials [4,5]. But such handbooks are not fully useful for acquiring knowledge outside of the corresponding training system. Sometimes they are assigned to the student with a note that only the person whose name is put on the cover can legally use the information contained therein [6,7]. This is due not only to the desire to protect the know-how, but above all to protect against misinterpretation of the information contained there by the untrained user.

Most often, a decompression system is developed with a high level of knowledge of the future user, which justifies the inclusion of only a sparing commentary [8]. It is typically constrained to the exclusion of responsibility[10] of the entity developing the decompression system.

This particular way of realising the process of introducing specialists to use the decompression system is justified by certain barriers in perception. Diver's skills should be considered rather in terms of highly qualified craftsmanship skills[11], which are acquired through an appropriate training system. This does not only concern the ability to use diving equipment, but also decompression systems. It is possible to describe many of the conditions for a correct approach to underwater planning [9]. The number of special situations is so large that teaching them in a single cycle would be extremely long and boring, making it problematic to demand its application. This can be compared to learning all the options and capabilities of a multifunctional electronic device such as a smartphone. As a rule, such comprehensive knowledge is not passed on to the user, as the functions not used on a daily basis will be quickly forgotten.

One can imagine divers to be as selected and trained as astronauts. That they are people with higher education in several fields of knowledge, with considerable practice in aviation and specially trained to achieve extraordinary fitness[12]. Going further, we could assume for a moment that a car driver should be an educated mechanic, trained similarly to professional passenger aircraft pilots. But to postulate such an approach would at best be met with ostracism or, in a worse scenario, with the accusation of lacking an adequate reference to reality.

Modern cars are no longer supplied with technical instructions for their servicing[13]. Nor are they supplied with precise technical descriptions. The same applies to decompression systems. Sometimes the decompression systems are classified and their implementation requires the involvement of the first user or developer of the decompression system. Sometimes information on the assumptions for decompression systems are patented, but even then the scope of the disclosed know-how is limited [10].

In military systems and high-tech commercial institutions, efforts are made to transfer knowledge about the decompression systems used as accurately as possible. Even in such cases, however, there are not enough comments to the tables provided. They are replaced by mandatory operational risk analysis [11]. This forces the user to undertake his own studies or participate in additional courses in order to acquire the skills to conduct such an analysis. In the event of an accident or potentially dangerous situation, the absence of such a document, or its perfunctory preparation, constitutes an aggravating factor for those responsible for the planned diving operation.

In most cases, the user would like the manual to be as comprehensive and informative as possible so as to ensure that all possible situations are described in it. These requirements are in mutual contradiction[14] and for this reason such an instruction probably does not exist in any field[15].

CONSERVATISM

In the case of factors that increase the possibility of symptoms of decompression sickness DCS, it is possible to compensate for the danger by using extended decompression. This procedure is called conservative or simply referred to as conservatism. Conservatism κ can be implemented in various forms. An example is selection of a greater depth than the depth of exposure from the table. This recommendation also applies if the exposure depth is provided in the table. Most often, the level of conservatism for a selected decompression schedule is increased by artificially adopting a longer stay for a selected exposure depth, as in the case of the air diving system used in the Polish Navy.

In the research on the acceptable values of partial pressure gradients for the decompression process, the concept of the so-called grey zone is introduced. This grey zone contains gradients which should not lead to the occurrence of symptoms of decompression sickness DCS, provided that there are no additional factors overlapping with the decompression process. The upper limit of the grey area are the maximum permissible gradient values[16]. The permissible lower limit for the grey area, which is often adopted in the range of [75,80]% of the upper limit[17], is rarely described. At this point the so-called zero conservatism κ=0% is usually established. The maximum conservatism κ=100% is related to the zero partial pressure gradient. For κ=100% decompression does not occur. If, therefore, decompression is planned well below the grey area, that is to say, with considerable conservatism, it is to be expected that the impact of the materialisation of some additional aggravating factors can be compensated for. However, if decompression is planned close to or within the grey area, additional burdens[18] arising in a particular diving process may lead to the occurrence of symptoms of decompression sickness, despite the correct choice of decompression profile based on its parameters.

The responsibility of the dive planner and the person who is in charge of the dive is to assess the level of conservatism applied in relation to the estimated residual risk *R* of decompression. This can be done by conducting a thorough analysis of this risk *R* based on expert knowledge gained through experience.

WORST-CASE SCENARIO METHOD

The worst-case scenario is commonly used for estimations. In diving technology, its limitation is sometimes needed, as taking into account all circumstances that increase the risk of DCS may lead to a lack of a good solution. For example, using Table 3MW, a maximum of two factors are considered [8]. The materialisation of more disturbing factors does not entail the need to increase conservatism when implementing decompression.

VARIABILITY

The decompression process is most often controlled by changes in the ambient pressure affecting the diver's body during exposure[19] and changes in the concentration of components of the breathing mix. Most often, any other factor influencing the balance between the pressure of gases in the tissues and its partial pressure in the breathing mix is treated as a factor disturbing the decompression process.

A change in the pressure takes place by means of a controlled change in the depth in the water or a reduction in the pressure in the habitat. This decreases the pressure of the breathing medium administered to the diver, e.g. from the breathing apparatus or habitat atmosphere. With the change in pressure, the partial pressure of the breathing mix components decreases to a level lower than its tissue pressure. The difference between the partial pressure of a breathing mix component and its tissue pressure creates the necessary gradient for diffusion processes allowing gaseous exchange. However, such a change can also be caused by changing the composition of the breathing mixture. A change in its composition will have the same effect of creating the required partial pressure gradient even at the same pressure value. The method of decompression without a change in pressure is called isobaric decompression, which can be carried out either with or without a modification in the composition of the breathing mix.

For example, supplying a man who has never dived before with oxygen to breathe at sea level produces a partial pressure gradient of nitrogen of about 78 kPa, causing a specific "washout" of nitrogen from the body. Similarly, after the end of a dive, with the use of air as a breathing medium, a certain nitrogen charge remains in the body. This means that the pressure of nitrogen in tissues will be higher than the partial pressure of nitrogen in atmospheric air. The resulting partial pressure gradient will be the driving force behind the process, which will lead to its elimination during surface isobaric decompression without any changes in the composition of the breathing mix.

Both described methods of producing partial pressure gradients are most often used during dives with artificial breathing mixes. For example, when diving with helium-based breathing mixtures, in addition to lowering the pressure, decompression breathing mixes such as various types of nitrogen-oxygen mixtures or air can be used at the same time, while for additional acceleration of the decompression process, oxygen can be used in its final phase.

However, the partial pressure gradient produced is also influenced by a number of other factors, of which the following are very important: temperature, physical exercise, respiratory resistance, compression, immersion, etc. It is rare that these other factors are used to control the generated gradient. It is most often assumed that they should be kept constant. In some cases this is not possible and thus these factors are treated as additional decompression loads.

RISK FACTORS

The Polish Navy traditionally adopts certain factors that increase the risk of decompression sickness DCS when a diver performs hard work

- diver is overcooled/overheated,
- a dive is an element of diving cycle,
- diver is untrained or has an individual predisposition to suffer from DCS,
- diver is obese or over 80 kg in weight,
- diver is over 40 years old

The list is not complete and it could be extended to include for example:

- specific hazards associated with the diving equipment, ancillary equipment, diving technology used, etc.,
- breathing resistance,
- decompression to less than atmospheric pressure or air transport following diving,
- local compressions caused by suit and equipment,
- forced position during work or decompression,
- flooding of the suit,
- diet,
- use of food supplements and medicines,
- dehydration, etc.

Some of the factors interfering with the decompression process are summarised in Table 1.

No one is likely to question the impact of the aforementioned factors on the increase in the risk R of decompression sickness DCS. However, the interpretation of these factors is usually controversial and therefore demands that they be precisely defined. It is difficult, sometimes impossible or even unreasonable to define many of the factors that increase the risk R of decompression sickness DCS in general.

RESEARCH

Most often, work on decompression is modelled on classical research in physics. In the initial research process, efforts are made to establish as many parameters as possible at the assumed level, modifying only those that can be controlled and reproduced with great accuracy and precision. The impact of changes in other parameters on the decompression process is then gradually examined. First with the set values of part of the parameters, then with the simultaneous changes of an increasing number of them. During the research various strategies are adopted in order to determine as precisely as possible the functional relationships which define the influence of individual parameters on the decompression process.

Tab. 1

Possible factors causing decompression accidents [12].

1. Reduction in blood circulation due to: obesity, hypothermia, physiological deterioration of circulatory efficiency (e.g. in elderly people), previous cardiovascular or diving illnesses, mechanical compression (e.g. of diving suits, no changes in position during decompression), etc.
2. Increase in the carbon dioxide content of the inhaled breathing mix or its accumulation in the body (hypercapnia) caused, inter alia, by: poor diver's condition, effort, presence of dead spaces in diving equipment, high density of the breathing mix, etc.
3. Considerable effort prior to diving and muscle acidification occurring afterwards. It is recommended to take 3-6 hours of rest before diving (depending on the conditions of the future dive), and it is absolutely prohibited for a tired diver to dive.
4. Alcohol consumption prior to diving and prior to the end of decompression (also during compulsory surface rest, after diving, when isobaric surface decompression occurs). Alcohol reduces the surface tension of blood, which facilitates the formation of gas bubbles. It is recommended that 12 hours before and 12 hours after the dive, no beverages containing alcohol should be consumed.
5. Dehydration is often disregarded as a factor that can lead to decompression problems. Ignoring dehydration, however, may lead to decompression problems, despite the observance of a number of other recommendations. Most often dehydration occurs in the following cases: • For long dives in salt water in a wetsuit. In this case water loss occurs through osmosis (especially important when using an open-system water-heated suit). • Hydrostatic pressure can cause increased diuresis. • Overcooling can cause increased diuresis. • Weightlessness causes increased diuresis. • During breathing with a dry breathing medium, dehydration occurs due to evaporation. • Caffeine, theine and alcohol cause increased diuresis. • Some groups of medicines cause dehydration and many increased diuresis. Divers may only take medication under the supervision of a doctor. • Anxiety and nervous tension can cause increased diuresis. Increasing the level of fluids in the body (rehydration) is recommended to increase diving safety. It is best to administer mineral water or a limited amount of fruit juice for this purpose. A diver should drink a lot a few hours before the dive. Hydration before the dive should take into account the diving conditions. It is not always possible to urinate freely during diving or decompression. If the diver is decompressed in a dry chamber with the possibility to pass urine, fluids should also be provided during decompression.

Tab. 1 cd.

Possible factors causing decompression accidents [12].

6. Injuries such as tearing of tissue. In the areas of injury, a free gas phase may form and not only in such obvious cases as in pulmonary barotrauma but also in minor skin injuries.
7. Diving during symptoms of poor physical and/or mental aptitude, e.g. hangover symptoms, sleep deprivation, fatigue, menstrual symptoms, headaches, disease symptoms, etc. These factors reduce the concentration of attention and thus lead to the possibility of confusion, e.g. when checking the decompression profile, measuring the depth or length of stay, etc.
8. The use of dietary supplements, headache remedies, oral contraceptives, stimulants or anti-stress agents, active plant-based products, such as herbal teas, may not be recommended before diving. One of the reasons for the harmful effects of such products may be the 'contamination' due to persistently high concentrations of chemicals in the blood. This may lead to an easier formation of a free gas phase. Some chemicals such as alcohol (alcohol is a component of many liquid drugs such as cough syrups) change the surface tension of the blood, thus facilitating the formation of the free gas phase in the blood.
9. It is important to consider various types of implants, even such typical materials as fillings of treated teeth. There are known cases of induction of tooth pain with poorly placed or improperly selected fillings. In these cases, it is necessary to consult one' s dentist about the possibility of diving, and when treating teeth, it should be noted that the patient practises diving.

Most often, research on decompression focuses only on determining the function of the influence of two variables on the decompression process: the composition of the breathing medium and the decompression profile, understood as the influence of ambient pressure as a function of time. Most often, only simple trapezoidal profiles[20] are tested in the laboratory environment.

In order to determine the level of risk caused by the omission of known and unknown interfering factors, research is conducted by building statistical models on the basis of the results of conducted experimental dives under simulated or real conditions. If such work is carried out in a cycle of scientific research under laboratory conditions, it is referred to as validation studies.

In addition to scientific research, monitoring of the hazards occurring during the operation of the decompression system in real conditions should be carried out. On this basis, risk models are being built, similarly to epidemiological monitoring. Monitoring is carried out in order to establish whether the level of conservatism taken into account is high enough to mitigate the impact of disturbing factors occurring during the actual operation of the decompression system, other than those which were examined during the laboratory tests. Monitoring must take into account the impact of elements of the system, other than the decompression system, but having an indirect impact on the decompression process.

For example: general development and pressure training programme, cycles of applied biological regeneration, health care and physiological tests, control of hygiene, diet, impact of underwater tools used, specific tasks, relaxation and psychological support, impact of water, underwater, land and air transport, etc.

The level of conservatism should be increased if it is found that the adopted levels do not adequately reduce the level of risk to the decompression system, even if it is necessary to return to the laboratory testing stage for this purpose.

If the system seems too conservative, the level of conservatism can be gradually reduced. A reduction in the level of conservatism can be achieved not by manipulating decompression parameters, but rather by studying the impact of the factors in the diving system on the safety of decompression. For example, in the Polish Navy, similarly to other countries, a system of periodic medical checks is in place as part of the admission to the profession of diver. Such a system does not have a function for supporting medical services for divers, which should strengthen the protection of their health. It is merely a bureaucratic barrier required to continue working as a diver. Such a system can be experimentally replaced by a doctor dedicated to a specific diving group. The responsibility of such a doctor would be to keep a group of divers in a good condition to perform combat operations.

The scope of his or her responsibility would be to collect the obligatory results needed for the assessment and to transfer them in due time to the existing central register. Only accredited centres could commission the tests. Thus, he/she would replace the central selection committee by making a decision on his/her own. However, in this case he/she could apply health care treatments through additional tests, supervision, training recommendations, biological regeneration treatments, hygiene control, nutrition, referral to rehabilitation treatments or performing them independently, conducting anti-stress classes, organising leisure activities, etc., just as it operates in the case of athletes' health protection. Such a system would also provide an opportunity to build a bond resulting in a relationship of trust. Therefore, many of the valuable comments would not be kept secret from medical staff. The introduction of such a system could take place on a pilot basis over a three-year period in one particular military unit, after which it would be possible to compare it with the traditional solution.

The following example describes a typical element of a test given to check a system's immunity to interference. An element is removed from the system, a new or redundant element is introduced or replaced and the impact of these changes in the system structure on the processes that the system should efficiently support is examined. Such system improvement should be a permanent activity, as each system tends to degenerate rather than self-improve. The system is most often degraded by the introduction of bureaucratic structural elements, the effects of which are not supervised and evaluated, but introduced on the basis of arbitrary decisions.

The lack of a systemic approach sometimes results in informal grass-roots changes. For example, in the Polish Navy, the supervision of the safety of diving operations is not based on a scientific method of assessment or application of the process approach described above. Hence, over decades, the diving practice of permanently elevating conservatism with air expositions has persisted. In the statistical staff assessment, this results in the opinion that the air tables used in the Polish Navy are very conservative [8]. This is not confirmed by laboratory tests carried out when properly planning the exposure. Under controlled laboratory conditions, an excessive amount of free gas phase is observed in venous vessels [13]. These tests were carried out in connection with securing work on new technologies by divers using air charts. Although these were not systematic studies on the safety of the air tables used, it can be concluded from the measurements carried out that rather than being conservative, the tables were actually developed under the assumption of a low level of conservatism. A brief analysis of the conservatism management procedures recommended with these tables, together with the occurrence of a moving gap between exposure times in the tables, shows that low conservatism was probably at the heart of the concept behind their development.

OXYGEN TOXICITY

Under saturated diving conditions, the most important form of the toxic effect of oxygen is pulmonary oxygen toxicity. When diving outside the saturation zone and from the saturation plateau, the threat of central oxygen toxicity of CNSyn is significant. For special procedures[21], for example, oxygen diving, an important form is also the somatic oxygen toxicity [14].

When studying decompression, it is important to point out that its planning is a kind of competition between the risk of various forms of oxygen toxicity and the risk associated with decompression sickness DCS for the most effective decompression profile possible. This can be seen in some decompression systems, for example in US Navy tables for operational Heliox Hx dives [11]. These tables are not planned for a specific[22] Hx, but for a specific range of Hx composition. When planning a dive, the ranges of maximum allowable oxygen partial pressures and the duration of exposure to them are considered first. The diving process may then be considered in terms of limitations related to the risk of decompression sickness DCS based on the partial pressure of helium in the inhaled breathing mix.

The efficiency of decompression, understood as minimising the risk R, is often equated with minimising the time spent in the aquatic environment. Reducing the time spent in the aquatic environment minimises the risk posed by it: possible malfunctions of diving gear and equipment, overcooling, stress, loss of buoyancy control, inconvenience associated with relatively low ergonomics of the diving gear and equipment, weightlessness, distorted field of vision, etc. Minimisation of the time spent underwater can be achieved by special technical equipment, such as diving from a bell or underwater vehicle, with possibly swift transport under pressure to a hyperbaric habitat, where decompression can be continued without risk of drowning. However, this equipment is expensive both in terms of investment and operation, hence not available to a wide range of divers. In combat dives it is usually not possible to use such equipment. Therefore, it is possible to increase the effectiveness of decompression by accelerating it. Diving outside the saturation zone requires oxygen to be operated under relatively high pressure, which poses a threat of the occurrence of central oxygen toxicity symptoms CNSyn. Therefore, when analysing the residual risk R of symptoms of decompression sickness DCS, the risk of symptoms of CNSyn should also be considered.

PROCEDURES

The specificity of some diving procedures may further increase the risk R of developing not only symptoms of DCS but also other diving diseases DCI.

For example, such an accompanying threat can be hydrostatic imbalance. With the use of special diving apparatuses with semi-closed respiratory circuit, a suction effect produced by negative pressure of the respiratory system may occur [15]. The phenomenon occurs in some positions of the diving apparatus relative to lung centroid [12]. This effect causes narrowing of the bronchioli and hinders gas exchange. With prolonged exposure it can lead to the appearance of fluid in the lungs[23]. This effect is well known among long-distance high-performance swimmers exposed to intense cooling and considerable effort [16]. At greater depths, it may be caused by an increase in respiratory resistance. Such an effect is not limited only to special devices, but also applies to open-circuit equipment, for which the respiratory support has not been properly set up, when cooling occurs as well as intensive effort [17].

Another example is carbon dioxide CO_2 retention[24]. Regenerative apparatuses pose an additional risk of a malfunctioning carbon dioxide scrubber. A moderately increased partial pressure of carbon dioxide may counteract a decrease in respiratory action when diving with high partial pressure of oxygen. Therefore, originally the diving apparatus was designed as a system with large dead spaces[25]. However, it has been found that such a solution, by eliminating one threat, introduces another. Carbon dioxide accumulates in the body because the affinity of CO_2 to haemoglobin is significantly lower than that of oxygen, hence its retention in the body, which may lead to hypercapnia. However, significantly below the threshold of hypercapnia, a considerable effect of CO_2 retention appears on increasing the risk of central oxygen toxicity CNSyn. It is associated with the effect of limiting the peripheral flow by CO_2 and increasing brain blood flow. The influence of CO_2 retention on the possibility of developing DCS is caused by the same phenomenon.

Passive heat protection with low-conductivity gases may affect the increased risk of symptoms of DCS. The idea of using such thermal protection was promoted several years ago, and is still occasionally discussed nowadays. The use of Argon Ar for passive protection against heat loss in dry-type suits was intended to extend the period of time it was possible to remain in the water. However, Ar migrates through the skin, then through the bloodstream and lungs, to the respiratory circuit of a regenerative diving apparatus. If the breathing space of the device is not sufficiently ventilated, the Ar retention may reach a level that disrupts decompression processes.

Argon was used in diving experiments to simulate changes in breathing mix density, hence the decompression parameters for this gas are known. Argon also accompanies air diving, as its contribution to atmospheric air is important, thus it is taken into account when developing air decompression tables. However, even a slight increase of its content in the breathing mix, especially during long periods of stay, the decompression for argon mixtures must be significantly prolonged.

Therefore, the use of Ar for thermal protection is an important problem for planning the correct decompression schedules.

An important element of the operational diving scenario is a change in the breathing mix and the resulting counterdiffusion phenomena having a significant impact on the safety of decompression. These problems have been described earlier and will not be discussed in more detail here [18].

Some diving scenarios pose a greater risk of DCS than others. Among the dives that pose a potentially greater risk of DCS are saw-shaped dives, yo-yo dives, multi-level dives, and frequent repeated exposures. The selection of an unsuitable diving sequence, with repeated or repetitive diving procedures, may also pose an additional risk of DCS. The potential increase in the risk of these procedures is associated with the disruption of the decompression process. The main route of decompression is gas exchange between the tissues and lungs via blood[26]. Ideally, this exchange should take place in the bound[27] or dissolved phase[28]. However, part of this exchange also takes place in the gas phase, constituting the nuclei of the gas phase in the blood. The lungs are not always able to filter out the resulting gas phase, which can pass through an intrapulmonary arteriovenous anastomosis in the lungs[29] [19].

Such undisturbed physiological function of the lungs is popularly called a lung filter. The enlargement of the nuclei of the free gas phase to a certain size triggers the activation of the intravascular coagulation cascade causing blood clotting, similar to the initiation of wound healing. This process is called complement activation [20]. In these types of dives, at certain stages of execution of their scenario, there may occur cycles of compression and decompression of the free gas phase that disables the pulmonary filter and the free gas phase through the lungs and heart to the arteries. It is assumed that during decompression, a free gas phase may occur in venous vessels in sizes which do not cause complement activation. And for the same conditions, they should not lead to the secretion of a free gas phase in arterial vessels due to the pressure difference between venous and arterial circulation. However, rapid manipulation of depth changes may cause a free gas phase to pass to the arteries and accumulate there and agglomerate to the extent harmful to the organism. An example is the observation of a surprising increase in the incomprehensible incidence of symptoms of decompression sickness DCS in divers working on fish farms [21,22]. This was surprising because they performed only short dives at shallow depths [12].

The decompression tables most often refer to the depth[30] expressed in mH_2O for fresh water[31], but diving in seawater or suspensions[32] exposes the diver to higher pressure than even an accurate depth measurement would suggest. Most often the depth is determined by means of a pneumatometer[33] measuring directly the pressure exerted on the diver at the dive depth. As with any measurement, this one is inherently flawed. In addition, there exists a discrepancy in the interpretation of the exposure pressure measurement point[34]. Therefore, even if the dive depth measured with the pneumatometer appears in the decompression tables, it is recommended to take the next greater one to determine the decompression profile[35].

ELEVATION

Often decompression systems are dedicated only to marine applications where the reference pressure for isobaric surface decompression is the normal pressure. If the reference pressure is different, decompression schedules may be inadequate for a system developed for marine conditions. This process is encountered when diving in mountain lakes. Also, it is a problem that occurs when air transport is planned immediately after the dive.

Some tables take into account the elevation of the body of water above sea level, giving different decompression schedules for the adopted elevation ranges. For tables without such options, different forms of compensation may be proposed [23].

Decompression systems for military use should specify the possibility of immediate air transport after the dive, as this enables the planning of diver recovery by air [24].

Decreasing the pressure value, as in the case of flights by airliners or transport helicopters, can cause so serious imbalance in the gas pressure in tissues as to trigger symptoms of decompression sickness DCS. Changes in atmospheric pressure during flight in an aeroplane[36] or helicopter may affect the equilibrium conditions after decompression owing to a drop in pressure at the flight altitude[37]. This can cause an imbalance and a free gas phase, leading to symptoms of DCS. The procedures for estimating decompression should specify the threshold at which surface isobaric decompression will take place.

WORK

In some cases, carrying out thorough scientific research does not translate into the possibility of using it in practice. An example of this is the limitation of the amount of work expended. Even if it is possible to establish the percentage of the increase in the risk of DCS as a function of the workload in a unit of time, diving supervisors or divers are not able to measure the effort spent during the diving process. In addition, the safely spent work strongly depends on individual predispositions, showing at the same time fluctuations for the same individual, depending on his or her mental state or current physical fitness[38].

The effect of exertion on the increase in the risk of DCS is usually caused by the transition to anaerobic metabolism and the secretion of lactic acid in the muscles, as a biochemical metabolite of anaerobic metabolism. Lactic acid from the muscles[39], penetrates the blood causing a decrease in the exponent of hydrogen ions pH in blood, causing significant changes in the effectiveness of oxygen transmission through the blood [14]. A decrease in the efficiency of oxygen transmission results in abnormal gas exchange between tissues and blood. In this way a biochemical barrier is created to eliminate excess gases dissolved in tissues during the decompression process. In such a case, the process of safe acceleration of decompression with oxygen or decompression mixtures is not in accordance with the model adopted in the research conducted to develop decompression schedules for safe decompression, so it may be inadequate. The impact of a decrease in the efficiency of oxygen transport through haemoglobin on the risk of DCS would be difficult to reliably model, hence this effect is not taken into account quantitatively in decompression studies.

Heavy work can only be conducted during saturation dives, because after the work is finished, the divers can rest whilst still at the saturation plateau, thus restoring their regular homeostasis. Then it is possible to proceed with standard decompression. In dives outside the saturation zone such a possibility does not exist, which is why the effort for such dives is limited.

For decompression disturbances, it does not matter how lactic acid has developed in the muscles. Distant effects may come from the previous dive, the current dive or other pre-dive effort. Even normalising the pre-dive rest time will not do much good if excess effort is spent outside this limit, with insufficient physical training, leading to extensive lactic acid secretion in the muscles. This is because the effects of spending work on anaerobic metabolism can last for several days. It is unrealistic and unnecessary to demand that the rest time after a dive should be several days. The state of readiness of a diver must be assessed by the diving manager, who can rely on lactic acid measurements in the blood.

It should be remembered that after the dive, during the stay on the surface isobaric decompression continues to occur, which has a direct impact on the amount of effort it is safe to exert following the dive. Therefore, the decompression system should include reliable limits of recommended rest time in the phase of isobaric decompression after the dive. However, the indications from the validation of the system should only be considered as an averaged value, as it may need to be extended depending on diving conditions or training status. Also, the individual capacity to compensate for post-dive changes is of great importance. It should be noted, however, that they may fluctuate depending on the circumstances and the current fitness levels of the diver.

It is generally considered that physical exercise during decompression has a negative impact on the decompression process [25]. There are also credible indications suggesting the very opposite [26]. Undoubtedly, movement during decompression causes additional emission of a free gas phase into venous vessels. With an instrument for the detection of free phase gas or a typical ultrasound scanner it is easy to ascertain. When conducting free gas phase detection in venous vessels, using the Doppler ultrasound technique, two types of measurements are carried out: in the rest phase and in defined motion [13]. The movement is to specifically force an increase in the proportion of free phase gas in venous vessels.

As mentioned earlier, when estimating the acceptable values of partial pressure gradients of gases during the decompression process, the existence of the so-called grey area is assumed. This includes partial pressure gradients, which should not lead to the occurrence of symptoms of DCS, provided that there is no overlap in the course of decompression with excessive, additional factors that burden the diver's body. If the decompression is planned below the grey area, the working of the muscles during decompression causes increases and decreases in pressure in the muscle tissue, resulting in a mechanical "pumping" of an additional portion of gas from the tissues to the blood, intensifying the decompression process. However, if the decompression is planned near or within the grey area, the additional "pumping" of gas into the blood may contribute to the occurrence of DCS symptoms.

TEMPERATURE

In general, changes in ambient temperature have a significant impact on the homeostasis of the human body, and therefore they also have a considerable effect on the gas balance in the diver's body. Every temperature variation in the diving process has an impact on the process of gas exchange. For example, during research on decompression, a fast hot shower after the dive is used to provoke skin symptoms of decompression sickness. This effect is sometimes not easy to predict, for example, for air diving the best effects were achieved when diving took place in a relatively cold environment and decompression in a warm environment [27]. However, for other dives, this relationship may be different.

The influence of temperature can be explained by physics. The most common phenomenon is that the solubility of gases in liquids decreases with increasing temperature. However, the mechanism of inducing symptoms of the DCS is more complicated, for example, warming of the skin while taking a bath is accompanied by dilatation of blood vessels of the dermis and superficial layers of subcutaneous tissue and a decrease in overall blood pressure, causing an imbalance of gas in the tissues and blood, and creating favourable conditions for the formation of a free gas phase. The Polish Navy uses the technique of transporting the diver in a dry bell following deep diving. After evacuation of water from the bell and its sealing, it is transported to a hyperbaric complex which the diver enters under current pressure. The first skin symptoms of the DCS are already observed whilst in transit to the complex, particularly in the hands and face area[40]. These symptoms are compounded during a dive protected by helium-based[41] artificial breathing mixes, when the diver's comfort has been protected only by passive heat protectors. These symptoms intensify when the diver moves into the warm environment of the hyperbaric chamber of the complex. Then they gradually disappear. This effect is not observed during saturation dives, when comfort of the diver is ensured by active thermal protection measures[42].

Changes in the diver's thermal comfort are usually accompanied by different phases of the dive, such as the process of preparing to dive, the time spent in the water environment and the time after the dive. Thermal comfort is often subject to quite unexpected changes. For instance, when preparing for dives in cold waters without active thermal protection measures, it becomes important to choose appropriate protective clothing. When selecting thermal protection, it is necessary to take into account the level of planned effort and time of stay. When planning a relatively long stay, it is not possible to assume a long-term effort, therefore a relatively effective outfit for a diving suit is chosen. However, when a considerable effort is required, for example when a diver is operating in a strong underwater current, he will need to work hard to fight against the current, resulting in the diver unexpectedly overheating. On the surface, a person can partly undress[43] and then dress again, whereas under water this is usually difficult[44]. Overheating increases the physical exhaustion of the diver during the diving process, which directly translates into safe decompression.

Further unexpected changing of thermal comfort may occur as a result of flooding of a dry suit with water. If flooding occurs during the initial submerging or earlier on in the dive, the dive can usually be interrupted or shortened in order to avoid escalation of the hindering conditions. However, if the suit floods late in the dive, or during the decompression process, it is usually not easy to counteract the resulting problem situation. If the decompression tables in use are designed to use surface decompression, there is a way to shorten decompression in water. Surface decompression requires having the decompression chamber in close proximity, as surface decompression procedures guarantee a time no longer than [5,7] minutes for a rapid ascent from depth, transport to the chamber, partial removal of diving gear and return to pressure in the decompression chamber [28]. This time is extremely short, so when it is planned to use a surface decompression procedure, it is important to practise all the operations to carry it out, because the resulting extension of this time may cause serious symptoms of decompression sickness [29].

Dangerous effects of overheating are observed in safety divers. The safety diver cannot completely remove the diving gear, which means that he/she may overheat on the surface. Once in the water he/she experiences a thermal shock. During an intervention dive, he/she may be exposed to further overheating or, on the contrary, to relatively rapid cooling, depending on the action to be taken during the intervention.

SUCCESSIVENESS

When undertaking repeated dives, account should be taken of the remaining saturation from the previous dive. The decompression schedule should include planned stops aimed at reducing the divers saturation during isobaric decompression whilst resting on the surface after the dive. However, the surface decompression process is not the only factor setting limitations on the next dive. An important limiting factor is the mechanism of transition to anaerobic metabolism, which was described earlier. Often the effect of saturation disappears after just 3 hours[45], but the effects of intensive effort can persist for 2-3 days. Therefore, if a diver had worked hard during the previous dive, the typically prescribed rest period on the surface may be inadequate.

Blood pH measurements[46] may only eliminate the diver during the initial diving test, as there is no reliable model taking this parameter into account when planning safe diving operations.

Consideration of the impact of expended effort, especially in a series of dives, is an important premise for the process of planning diving operations. Ignoring this fact is an error. The decision as to the proper course of action in such a case may only be entrusted to the knowledge, experience and reasonableness of the decision-maker, which constitutes his/her sole responsibility in this regard[47].

PREDISPOSITIONS

During a diver's training, it is important to collect anthropometric and physiological data related to decompression safety. The basic data sets include nutritional status, total body weight, muscle mass and fat mass. Also relevant are the level of care given to the teeth, skin, eyesight, throat and ears etc. What is important is the current, general condition of the body's fitness with particular emphasis on flexibility, reaction to the long-term effort or work in a forced position, biological age, etc. Respiratory parameters such as: vital lung capacity, maximal oxygen uptake[48], ratio of oxygen consumption to lung ventilation, etc. play an essential role. Also other related parameters such as oxygen pulse, oxygen breath or bradycardia associated with descent all play a major role. Sometimes, owing to the specificity of the performed diving service, not all parameters are equally important.

In addition to the fitness tests, it may be useful to test for resistance to rapid compression and tolerance to oxygen exposure. Nowadays, the need for testing to exclude heart defects, such as the presence of a patent foramen ovale in the atrial septum[49], is gaining in importance.

The role of mind set and mental training is, relatively speaking, often disregarded. There is much evidence that mind set and the state of mental training plays an important, if not fundamental, role in extreme sports or dangerous work. Quite often the meeting of outstanding people who have proven themselves in extreme conditions is accompanied by the surprise that they are often people whose body structure, facial features or behaviour do not meet a common archetype. This shows that their distinguishing feature is mental rather than physical structure. Pre-diving predisposition is also important. This is not confined to the state of rest/lack of compliance with the prohibition to work prior to diving, etc., but also the mind-set resulting from the analysis of the situation, the current condition and the psychological burden caused by events that lie outside the realm of diving[50].

BODY WEIGHT

There is a general belief that an obese diver is at greater risk of developing symptoms of DCS compared to a slim diver. This conviction is associated, for example, with greater solubility of inert gases in adipose tissue than in muscle tissue. There is also a conviction that a perfectly built athlete is more resistant to severe decompression than a person with an average muscle build-up, which is probably anchored in the general archetype rooted in society. In some cases, such an understanding of reality may be inadequate.

All diving mammals have a significant reserve of body fat. They can dive to considerable depths, for example seals can dive down to 500 m and some cetaceans down to 3,000 m. Seals can remain underwater for about 20 minutes and cetaceans on average up to 50 minutes. Their anatomical structure, especially the "ribbing" of their lungs, is different from that of humans, which is why they are capable of diving to such considerable depths[51]. Nonetheless, the physical phenomena accompanying the diving process are the same. These animals likely suffer from DCS, just as it was probably the case with diving dinosaurs. These theories are based on studies of the skeletons of these animals and the finding of sterile bone necrosis. If this premise is accepted, it should also be assumed that such observations can only be made in older, if not aged, animals. However, the observation of marine mammals cannot be transferred directly to humans, due to the completely different structure and function of the peripheral part of the circulatory system. A thick layer of adipose tissue is the basic thermal insulation of these mammals. Through evolution, they have developed the ability to cut off the flow of blood to the subcutaneous tissue, so it is not saturated during immersion.

It appears that greater solubility of inert gases in fats than in water is essential in DCS induced by the counter diffusion process [18]. The difference in the solubility of inert gases in the presence of significant blood supply to adipose tissue seems to be less significant. However, in contrast to animals hybernating in winter, the blood supply of human body fat is poor and not particularly variable.

For reasons of thermal protection, it is sometimes inexpedient to require the diver to lose weight in order to significantly eliminate body fat.

A strong body build can be an additional burden when considering the risk of DCS. The developed muscle tissue consumes more oxygen during physical effort. The parameter of oxygen consumption per unit of body mass is one of the typical parameters taken into consideration when assessing overall fitness. High values of this parameter are an important premise taken into account when assessing athletes' training condition. In diving, good general training and high muscle mass may be a premise of increased risk of DCS. This may be the case if the muscle tissue has developed as a result of a workout other than swimming or diving. Strong muscle development requires efficient gas exchange. If the muscle build-up was caused by surface exercise training, it is possible that an efficient surface respiratory and circulatory system may not be efficient enough under external pressure. Those who exercise according to strength training, especially isometric training, can relatively easily switch to anaerobic metabolism. The harmful effects of this phenomenon on the decompression process were described in the workload analysis.

Muscles are relatively easily capable of pushing through significant amounts of gas dissolved in them during contraction. Thus, during the assessment of decompression risk, the gas emitted from the muscle and forced into the blood is measured by observing the amount of free fas in venous vessels [13]. Expanded muscle tissue can release significant amounts of inert gas into the blood as a result of effort, increasing the risk of decompression sickness DCS.

The principle of operation of semi-closed circuit apparatuses is based on ventilation models whereas safe decompression is planned based on the maximum reduction of oxygen content in the breathing mix inhaled by the diver. Therefore, the model is based on the assumption of maximum oxygen consumption by the diver. If a diver is allowed to dive with such equipment with an over-consumption of oxygen, the decompression schedule assumed for the diver may not be adequate.

LOADS

The load on the diver consists not only of the useful work he/she performs, but also of the load associated with it:

- respiratory resistance,
- ergonomic loads, such as: suit resistance, tools, diving gear dimensions, etc.,
- parameters of the aquatic environment: lift, buoyancy, etc.,
- operation and other loads connected with the necessity of continuous concentration,
- psychological burdens, etc.

Respiratory resistance is a serious contribution to the diver's workload. They are unavoidable when diving, for instance owing to the increased density of the breathing mix[52]. Their impact is taken into account during the process of developing and validating decompression schedules for the diving equipment concerned[53]. Inspiratory resistances are particularly harmful but moderate expiratory resistances can have a positive impact on the diving and decompression process.

The bronchial tree from the trachea to the bronchi reduces in diameter and is rigid due to the presence of resilient bronchial cartilage in the walls. It is this cartilage that prevents the collapse of the airways when a person is breathing in a hyperbaric environment[54]. The muscular and terminal bronchiole are sufficiently flexible to allow them to be constricted or even closed, especially if a vacuum is also created as a result of the rapid flow of gas. The closure of the bronchiole leads to a partial stopping of the gas exchange and, as a consequence, to local hypoxia.

An increase in respiratory resistances can easily cause a disturbance in gas exchange. These effects are not considered when estimating the decompression procedure. Divers should be trained in conscious breathing to avoid disturbing the decompression process. Inhaling should take place slowly in a controlled manner, while during exhalation, resistance can be increased by clenching the mouth and performing a forced exhalation as recommended in cases of asthma.

Breathing equipment for both diving and inhalation should be checked as often as possible, not only for the tightness of its component parts, but above all because of the breathing resistances.

Any form of compression, which usually results in reduced blood flow, can provoke skin symptoms of decompression sickness[55]. With some types of diving gear, local compressions cannot be avoided, such as the neck seals and sleeves of dry-type diving suits, or the neck seals of diving helmets, etc. Research carried out to develop the decompression process does not take this into account.

A diver most often performs underwater work in a suit, which by limiting his movements increases the workload. It may also cause a tightening so significant that it results in shallow breathing and effects similar to those of asphyxiation[56]. It also often causes localised compressions which can lead to reduced blood circulation. This, in turn, can lead to local, painful symptoms of decompression sickness. Some local compressions are difficult to eliminate, such as the already mentioned sleeve seals or the neck seal of the suit, hence it is necessary to optimise them. Most often the diver is burdened with a diving apparatus which, similar to the suit, restrains his movements and causes local compressions.

Local body compressions can and should be counteracted during decompression in the decompression chamber. Divers often forget about it, so the task of reminding the diver about this lies with the staff.

When carrying out underwater work, the diver must assist in moving different parts of structures, often using different tools. The tools are usually designed in accordance with ergonomic principles, but the displaced structural elements are not. Underwater tools are usually heavier than those used on the surface.

Performing hard work underwater requires stabilising the diver's profile in the water, and in this case no simple methods exist which would take into account ergonomic principles. The stabilisation of the diver's position is most often achieved by applying variously distributed additional weights, such as: breast weights, weight belts, special footwear or other local weights. All these elements impose restrictions on movement, and the necessity to expend additional effort as well as cause local compression.

The use of some elements of equipment and tools is absorbing for the diver, which is why he or she cannot completely focus only on useful work, but also on the control of elements of equipment and diving parameters. For example, the lack of correct setting of respiratory resistances on the breathing gas supplied to the diver may result in a slight increase in respiratory resistance and, as a consequence, the need for additional breathing effort. Similarly to the lack of sufficient control over buoyancy, such resistance results in unnecessary addition exertion to counter it. This may result in anaerobic metabolism with all the consequences associated with it.

Controlling diving and decompression parameters is an absorbing activity. These activities require appropriate attention and errors can be significant. The concentration process is disturbed by the toxic influence of components of the breathing mix. When planning a dive, it is important to pay attention to this difficulty by giving the diver sufficient time to consider and, if possible, control his or her actions[57].

Negligence in the proper fitting and arrangement of equipment may cause local compressions and consequently lead to local, most often dermal, symptoms of the DCS. The approval for underwater work should be preceded by preparation involving a properly selected training course with consideration of the possible scenarios for underwater work. The commencement of work, on the other hand, should be preceded by preparation consisting in verification of all elements of equipment and current diving parameters

MENTAL STATE

The profession of diver requires moving in an environment to which humans are not adapted. This is why it is necessary to control the diving process with the use of measuring instruments, focus on hazards, whilst at the same time providing limited protection, based to a large extent solely on the possibilities of self-rescue. Diving can take place in situations causing agoraphobia, operating in isolation with limited possibilities of communication, difficult spatial orientation, sometimes in enclosed spaces and often darkness which increases claustrophobia, etc. This causes anxiety, compounded by a feeling of weightlessness, distortion of the image and dimensions of objects, exposure to cold, sometimes to a feeling of hotness, etc. These factors lead to physiological disorders, usually similar to seasickness. Such factors impede concentration and disturb the diver's emotional state.

Military diving is additionally accompanied by psychological problems associated with working with explosives, in the immediate vicinity of an opponent, with awareness of the existence of anti-diver barriers and active forms of combating them, etc.

Two extreme types of psychological adaptation are most often observed. One consists in displacing thoughts related to threat with thoughts about the various forms of individual compensation the diver might expect. The second consists in a pragmatic approach to threats, promoting a phlegmatic response to risk. The former gives a high degree of self-confidence and considerable accumulation of stress sometimes allows one to survive, but when the immunity barrier is exceeded, an anxiety attack is explosive and in most cases can no longer be contained. The second style of adaptation also creates the possibilities of working under stress, but exceeding the limit of endurance causes discouragement and resignation. However, it is possible to wake up from this torpor once the right impulse materialises. Depending on the development of any given stressful situation, it often happens that parallel natures can actively exist in humans as in Stevenson's novel: *Dr Jekyll and Mr Hyde*. It is possible to try to push the boundaries between them through adaptive training, however, it is a labour-intensive process.

It seems that psychological training also has a large impact on the safety of decompression. Theoretically, this mechanism can be explained, for example, by its influence on the process of secretion of stress hormones. Their action is based on direct stimulation of the receptors causing the contraction of blood vessels and hence an increase in blood pressure. This is accompanied by an acceleration of the heart's action, an increase in its stroke volume, an increase in diastolic pressure in the aorta and an increase in cerebral and coronary blood flow, pupil and bronchial dilatation. It also mobilises fat burning, inhibits intestinal peristalsis, secretion of digestive juices and saliva, and reduces smooth muscle tension. Of course, not all these changes must cause a direct or indirect increase in the risk of symptoms of decompression sickness, but any imbalance in the body is undesirable from the point of view of decompression safety. Controlling the fine line between entering a stressful situation and the outbreak of panic creates a handicap[58]. Such situations hindering the body's ability to facilitate the decompression process and making it more difficult for the symptoms of DCS to be identified.

TRAINING

The scope of diver training, apart from maintaining the diver's general psychophysical and physical health[59] should also include specialist diving, adaptive and psychological training, as well as care and hygiene procedures.

The conditioning adaptive training consists of a controlled swimming effort together with breath control. It develops a predisposition for underwater swimming. Such training may consist of underwater swimming with a held breath, and also with additional buoyancy[60] and strenuous distance swimming using the apparatus, etc. Complementary adaptive training comprises pressure expositions conducted in a hyperbaric chamber, allowing for respiratory adaptation to the hyperbaric environment and for undergoing decompression. Such trainings should be conducted continuously and the level of training used as a parameter to assess the degree of adaptation to work in a hyperbaric environment. The assessment of current level of adaptation to work in a hyperbaric environment can be carried out properly only according to the order scale[61]. To assess the state of training of a diving team it is not enough to obtain information about the currently completed training sessions, but the underwater operator should plan and personally supervise the training.

The above forms of training should be supplemented by adaptation to cold and thermal shock exposure. This training creates conditions for safe decompression by reducing homeostasis disturbances as a result of cooling. The training can be organised in a pool with unheated water and later in open water. The rule is not to use warm water before entering the pool or after exercise. At a later stage it is possible to enter the pool by jumping[62]. Gradually, diving training may be added using different options of swimming with held breath. Swimming with basic[63] and diving equipment may also be included. The level of workout load should be controlled by grading it properly, initially without being too strict on the trainee, for instance allowing the use of head warmers or warmers for any other body parts.

Training in the decompression chamber should be supplemented by elements of psychological training of resistance to claustrophobia. Of course, psychological training can be conducted additionally in an isolated form, for example in the form of meditation or anti-stress training. However, it is impossible to separate the elements of psychological training from general development training or specialised diving training. The psychological and diving training should also include elements leading to the following physiological reactions: hypoxia-induced sleep, aerobic blackout, choking, deep transition to anaerobic metabolism, respiratory stress, etc. Such training can be organised in swimming or diving pools, also during regular swimming or general development training.

The spatial orientation training of claustrophobic immunisation can be conducted on specialised obstacle courses. In our hydrological conditions, it is difficult to organise a training course adapting to agoraphobia. It can be carried out only in waters with high visibility and with faults occurring at great depths, as an element of diving or swimming in a bathyscaph. If this is not possible, it can be organised close to a technical infrastructure, such as an oil rig, using a multi-point underwater lighting set up to create an appropriate spatial exposure. Dangerous, but exploitable areas would be sites such as flooded quarries.

Diving in a different environment should be preceded by adaptation. Such adaptation does not only mean adaptation when changing elevation, as before diving in alpine areas. There is also a need for adaptation when changes occur in meteorological[64] or hydrological conditions[65].

DIET

Divers need to observe the general calorific recommendations and supplements for people performing hard work. However, the diet should also take into account specific requirements.

The centres of nucleation of the free gas phase growth can be inclusions from dietary supplements, dietary elements or medicines taken. Therefore, information on this subject cannot be ignored or trivialised. For example, there is a belief that fruit juices are a source of valuable vitamins and should be recommended for divers. In general, such a conviction is correct, also from the point of view of the desired hydration of the body. However, juices contain a significant amount of acids, which quickly reach the blood, potentially lowering the pH of the blood. The organism defends itself by using buffering effects that are potentially unfavourable from the point of view of decompression. The protective mechanism in the form of buffering the pH of blood is based on the processes of carbon dioxide emission, causing faster breathlessness or symptoms of wheezing. Similarly, a diet consisting of sour food may cause analogous effects.

A diet rich in fats causes fats to also be present in the blood serum above physiological limits. It is well known that high cholesterol content in blood serum favours its accumulation in blood vessel walls, which increases the risk of arteriosclerosis.

Plasma lipids are essential to facilitate the absorption of fat-soluble vitamins by acting as carriers of these vitamins. In relation to inert gases that are better soluble in fats, the lipids contained in blood may act as a carrier and/or storage medium. The gas storage function should change the character of the tissue from fast to slower.

PERSONAL FACTORS

Personal immunity or sensitivity to the effects of decompression may result from the natural presence of a free gas phase in the blood constituting a factor allowing for its growth during decompression. The free gas phase in the blood is formed mainly by the phenomenon of cavitation accompanying the beating of the heart[66]. The emission of cavitation free gas phase in the heart is largely dependent on the individual heart structure and especially the work of the valves. Experience in ultrasonography and the possibility of continuous performance of such tests still only gives the possibility of subjective evaluation of the influence of this factor on the safety of decompression, and therefore it cannot be generalised or normalised as yet. Personal resistance to strenuous decompression may be caused by increased perfusion of fat tissue through blood[67]. In this respect, differences are observed depending on gender and age.

Stress hormones mainly affect the cardiovascular system, thus improving blood circulation. They also increase the secretion of glucose into the blood. Stress hormones cause the whole reaction of secretion of various other substances into the blood. They are potential sources of growth of the free gas phase. Although hyperactivity causing a rapid increase in perception is, in many cases, a positive behaviour, when diving it can lead to an increased risk.

There is a strong conviction that individual immunity to the effects of decompression decreases with age. However, long studies of the occurrence of free gas phase in venous vessels show that the situation may be more complicated. A certain percentage of divers advanced in age, but still in good general physical condition and undergoing systematic hyperbaric training, do not show signs of DCS despite the presence of a significant amount of free gas phase in their blood[68]. Although this phenomenon is being observed, it is difficult to explain it on the basis of current physiological knowledge. The occurrence of these phenomena does not affect the general trend in age-related burdens, which make it necessary to moderate decompression regimes for older divers.

GENDER

The discussion on the gender impact on the safety of estimated decompression was triggered by publications on the risk of DCS in aviation. But after further analysis of the literature, it appears to the author, that noticeable differences exist in hypobaria, whereas in hyperbaria no such differences were observed, although studies were conducted on a substantial number of individuals [9,21,31].

However, there are a number of burdens associated with gender differences that have a significant impact on decompression safety.

To date, few scientific studies have been carried out on the impact of gender on the risk of the DCS. This is because almost all scientific research is being conducted with a view to military and commercial applications. Currently not many women are active in these fields. Currently, the Polish Navy has started recruiting women for diving roles.

If a woman can endure vigorous exercise during her menstruation, she should also be able to dive without major problems. If a woman alleviates her menstrual symptoms by taking painkillers, she should refrain from diving. Pre-menstrual stress[69] may cause some women to have a tendency to reduced environmental tolerance or mental breakdowns. In general, the question whether a woman can dive during this time depends on how she feels.

Many women dive in the first weeks of pregnancy when they are not yet aware of conception. During this time the foetus is particularly vulnerable to teratogenic factors[70]. The foetus should have an adequate level of oxygenation, neither too high nor too low. There is speculation that a free gas phase that does not cause problems in the mother[71] may 'attack' the foetus or placenta by restricting blood flow and thus reducing the foetus' oxygenation. Part of the procedures for treating DCS consists of recompression and administering oxygen for breathing. Some people believe that high oxygen partial pressure can be carcinogenic to the foetus[72].

Conclusions

The material presented could not provide an in-depth analysis of the academic literature. Although the literature on the safety of decompression is extensive, the reports tend to focus on individual cases without, as yet, making indisputable recommendations. Only very few of the authors present an analysis of the factors that interfere with the decompression process in the literature that is widely available [2].

Most of the presented problems stem only from the so-called good diving practice, which was collected by the Polish Navy specialists. These practices were taught on specialist courses but, probably due to the lack of their development in a consolidated form, they gradually disappeared. They were briefly described here and should be taken into account in the obligatory analysis of the inherent risk of decompression, although their interpretation has not been undisputedly confirmed in a methodically correct and a complete scientific cognitive process[73].

The diving process is only part of the combat operation scenario, hence the safety of the dive translates directly into its effectiveness. Developing and checking some of the predicted dive operation scenarios makes deep sense when looking for the optimal way to plan a combat operation.

Reference

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dr hab. inż. Ryszard Kłos prof. AMW
Polish Naval Academy
Department of Underwater Work Technology
81 – 103 Gdynia 3
ul. Śmidowicza 69
e-mail: r.klos@amw.dynia.pl

ORCID identifier No: 0000-0002-4050-3978

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[1] inseparably linked,
[2] residual risk which can no longer be minimised under given conditions,
[3] the assessment of the condition presented on the basis of studies and analyses,
[4] activities to test suitability at the assumed level of accuracy and precision,
[5]they are most often collected in the form of a case study and the conclusions of the case study are introduced as pilot recommendations for the use or usable patents that make up the good diving practice,
[6] knowledge not yet validated by methods and methodologies recognised as scientific,
[7] or a military transport plane,
[8] the pressure in the corridor cut off by the water can be much higher than would only be the result of it being below sea level,
[9] the decompression meter typically cannot take into account the residual risk,
[10] the most common comment concerns the use of the decompression system being at one' s own risk,
[11] to avoid pejorative meaning, these skills can be compared to the skills of diamond polishers, master chefs, etc.,
[12] this refers to professional spacemen, not people who are merely space tourists,
[13] at present it is becoming increasingly common that having servicing instructions requires a franchise agreement with the manufacturer,
[14] discrepancy,
[15] some believe that Jaroslav Hašek achieved such a goal by describing all the possible situations that could happen in the army in a relatively small work entitled "The good soldier Schweik",
[16] they are the results of tests carried out under controlled laboratory conditions,
[17] the maximum value of the permissible pressure gradient,
[18] materialisation of residual risk,
[19] without changes in total pressure, the diver could not leave the hyperbaric environment,
[20] most of even the simplest dives conducted in real conditions have a more complex structure for the decompression profile,
[21] for example: decompression acceleration, oxygen therapy, treatment of decompression sickness, etc.,
[22] this makes it possible to bypass the relatively cumbersome procedure for the production of correctly composed Heliox Hx, allowing a relatively wide range in terms of composition,
[23] similar disorders occur in distance swimmers and are associated with deep, rapid inhalations causing the collapse of the bronchiole,
[24] containment of carbon dioxide in the body,
[25] oscillatory circuit device,
[25] owing to the induction of skin symptoms of decompression sickness, there may also be direct gas exchange between the atmosphere and tissues through the skin,
[28] physically dissolved gas in blood plasma,
[29] IPAV,
[30] depth is the unit of measurement of length, although in this case it is a specific unit of pressure,
[31] the reference to fresh water is unambiguous, the reference to the depth expressed in units of sea water is ambiguous because it depends on the salinity of the body of water. In the past, a reference value to water density was given on the manometer; now, in order to standardise the units of measurement, it is assumed that $10\ mH_2O\ f.w. \triangleq 100\ kPa,$
[32] suspension in water of certain minerals, such as barite, is known as the process of producing so-called "heavy water". For example, such suspensions are used in the drilling industry to exert counter-pressure on the walls of a borehole. This name may be misleading, as heavy water is also called deuterated water. In this case, we are dealing with the development of permanent suspensions that increase the density of water. Diving at the same depth expressed metrically in water with suspended solids is an exposure to higher pressure compared to clear fresh water,
[33] pneumatometer is used to measure pressure at depth (it differs in design from the device of the same name used in medicine to measure the inhalation negative pressure and expiration overpressure) - it is a tube which is fed with gas so that it flows slowly and freely into the water at its end, at the same time measuring the pressure in the tube,
[34] e.g. depending on the diver's position in the water, from the point of view of decompression in the diver's vertical position, there is a significant difference in depth between the feet and the head; the most common assumption is to measure the depth around the diver's lung centroid,
[35] the accuracy of the method and the place of measurement may cause the error for the measured pressure to be comparable to the distance between the decompression stations,
[36] in airliners, cabin pressure can be reduced for robustness reasons - this way the aircraft can be constructed for smaller pressure variations, hence their construction can be lighter,
[37] in accordance with generally accepted guidelines, the pressure inside the cabin of passenger aircraft must be maintained at a level not lower than that corresponding to a stay of 2438 m above sea level (0.75 atm),
[38] just like in sport, where not only individual predispositions count, but also fitness at the time of competition. However, meeting these conditions does not guarantee success, because the lack of mental resilience during the competition itself can reduce the importance of predisposition and training,
[39] lactic acid present in muscles can provoke aching effects,
[40] it is connected with a gradual change of temperature, especially when during transport to the surface an additional process of lowering the pressure in the bell takes place,
[41] in this case, slight skin symptoms are aggravated by the phenomena of counter-diffusion [18],
[42] during a saturation dive, the bell usually does not function as a thermal habitat, therefore, even while in the bell, the divers use active thermal protection measures,
[43] for example, when chopping wood for firewood in freezing conditions,

[44] in some regions, special operations divers still prefer wetsuits, which are equipped with Velcro systems for attaching the straps of an unbuttoned suit; this allows for partial unbuttoning of the wetsuit underwater and clarifying it in such a way that it does not increase swimming resistance,
[45] it is widely believed that after 12 hours the effect of saturation is unnoticeable even after deep water diving,
[46] at present, such measurements usually do not present major difficulties,
[47] it is not possible to precisely define the significance of the premise related to the increased risk of decompression sickness for serial dives, because sometimes the safe interval between dives will be 12 h, and in another case 2 days, one will apply to the second dive and in another case to the subsequent dives,
[48] the maximum amount of oxygen that the body is able to uptake during intensive effort,
[49] from Latin,
[50] for example health issues within the family unit, financial situation, recent setbacks, etc.,
[51] the collapse of their chest with depth does not cause mechanical damage to the body,
[52] of course, lightweight breathing medium components are used, but usually for diving at considerable depths, hence there is an increase in its density compared to atmospheric air; even under normal conditions, the Dräger company has also advocated the use of a lightweight breathing medium components for filling fire-fighting breathing apparatuses [33],
[53] the adoption of an existing decompression system is possible but should be validated,
[54] ca. $20\ kPa$,
[55] more serious symptoms in the form of joint pain may also be possible, usually in decompression after saturation due to a bad body position during sleep, therefore decompression during the night time is not recommended and divers are not allowed to sleep during the daytime,
[56] similar to the suffocation effects caused by some snakes strangling their victims,
[57] it is good practice to ask the diver questions, as it not only gives him/her control over their actions, but also gives the diver time to adjust their gear and equipment and to reflect on the current situation,
[58] facilitating one process and at the same time making the other difficult,
[59] understood here as the current physiological state of the organism undergoing changes under the influence of external environmental factors,
[60] e.g. immersion to a few meters with or without a swimming board and with or without support of the diver's fins, or distance swimming at a shallow depth whilst wearing fins, with or without breath holding and with a swimming board,
[61] of course, adequate provision should be made to deal with incidents such as cardiac arrest,
[62] diving in a different climate or meteorological conditions,
[63] differences in the occurrence of thermocline, tides or diving in flowing water,
[64] also between muscles, tendons, in tendon sheaths or periarticular areas,
[65] as in marine mammals, humans may also have fat tissue that is well perfused through blood,
[66] despite an extremely high build-up of free gas phase in their blood, they do not show signs of DCS which would have occurred with a high probability when they were younger,
[67] as in marine mammals, also humans may have fatty tissue that is well perfused with blood,
[68] despite the extremely large accumulation of free gas in the blood, they do not have symptoms of DCS decompression sickness that would have occurred with a high probability when they were younger,
[69] Premenstrual Syndrome,
[70] factors from the external environment that affect the organism during its development inside the womb,
[71] the main blood vessels are larger in the mother than in the embryo,
[72] the organ of vision can be particularly easily damaged, as shown by observations made in infant incubators [32],
[73] however, the interpretation of the examples quoted here is based on current knowledge.