ANALYSIS OF THE RISK OF DIVING ACCIDENTS IN MILITARY AND RECREATIONAL DIVING

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ABSTRACT

The most common question that arose in the course of the analysis of the data concerned with the number of diving accidents in recreational diving as compared with the authors' own experiences working with military divers was why the number of accidents in recreational diving is substantially higher than that obtained in military diving. The comparison of factors having a direct effect on diving safety, the scope of depths reached, the manner of conducting decompression and divers' problems reported after diving completion allow to explain the reasons behind the common incidents occurring among recreational divers. The factors which had a very significant impact on safety level included diving frequency, adaptation to higher pressure conditions and overestimation of one's skills in undertaking challenges.
Key words: military diving, recreational diving, diving computers, diving accident.

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INTRODUCTION

Diving in military or civilian conditions (recreational diving) should be similar, yet based on our long-lasting experience we note that these are two completely different forms of underwater activity. The fundamental difference consists in the physical health requirements which military divers are expected to meet, and its absence or extremely narrow scope in relation to recreational divers. However, the most important element, which has an impact on the risk of an occurrence of a diving accident is also related to the process of diver training.

The said process in military conditions is long-lasting and continuous in character and starts with a basic instruction lasting several months, through cyclic practice of emergency procedures and performance of increasingly complicated underwater tasks. The entire training is based on performing dives under the supervision of an instructor with full medical and logistic support. Recreational diving, on the other hand, is a completely different domain, starting with the training itself to independent performance of dives.

A recreational diver undergoes a short training (several days) as opposed to a military diver (even several months). Recreational diving in its very definition is occasional, seasonal, without continuous training enabling to work out certain habits, reflexes, and, what is particularly important, without a cyclic revision of emergency procedures. The absence of pressure training and extended time of practice, the fact that the occasional diving which is undertaken usually takes a similar form, all contribute greatly towards the risk of an occurrence of diving accidents. Due to the lack of data concerning recreational diving in Poland, in order to present the problems of recreational diving, the profile of dives and causes of accidents, the authors analysed data contained in Diving Alert Network Reports on recreational divers in the USA and Canada from the years 2002-2007.

OBJECTIVES

- Comparative analysis of the causes of diving accidents in the years 2002 – 2007 between recreational divers from the United States and Canada and a group of divers of the Polish Army.
- Comparative evaluation of the effective safety rules in the aforementioned groups.

MATERIAL AND METHODS

Characterisation of the researched groups.

The analysis of diving safety among divers and trainees of the Diver Training Centre and the Polish Army in Gdynia in the years 2002 – 2007 was carried out on the basis of data contained in Diver Logs [1], as well as assessment results of the Military Maritime-Medical Committee.

The study involved 20592 hyperbaric exposures, including dives performed in open bodies of water, diving pools, exposures in decompression chambers and oxygen tolerance tests. It was participated by 1169 divers from the Military Diver Training Centre.

The comparative analysis was conducted with recreational divers from the USA and Canada who were not subjected to physical health qualification. The study was concerned with 8964 recreational divers who performed 115479 dives, as specified in the Diving Alert Network Reports for the years 2002 – 2007 [2-7].

METHODS

The study was based on data contained in the Diving Logs of the Diver Training Centre of the Polish Army for the years 2002 – 2007, which specified the quantity and type of dives, the number of divers and reports of the Military Maritime-Medical Committee in Gdańsk. Moreover, it was performed with the use of the data published in the Diving Alert Network Reports for the years 2004 – 2009 containing data for the years 2002 – 2007 on recreational dives performed in the USA and Canada.

The study included: Analyses of source documents and selection of groups subject to evaluation. Analyses of data on the researched groups and statistical analysis enabling formulation of conclusions.

STATISTICAL ANALYSIS METHODS

Statistical analyses were conducted with the use of Statistica v10 software. The provided diagrams present the structure of researched variables in time. The analysis included an investigation as to whether a statistically significant correlation exists between the risk rate of an accident occurrence % and the percentage of fatal accidents and each of the tested variables. The study was performed with the use of Spearman rank correlation, as the data present percentage values for particular variables. The obtained results can be arranged in a rank order.

The replacement of particular values with corresponding ranks minimises the negative effect of outlying points, as well as enables the carrying out of correlation analysis for measurable variables that are not characterised by a normal distribution. The said correlation adopts the values from the range [-1:1] defining the strength of correlation between the researched variables. The next part of the paper describes only statistically significant correlations.

RESULTS

The depth of dives.

Military dives are mainly performed to depths ranging from 0 to 10 m (80% of dives). Diving to the depth between 10 –20 m is much rarer, such dives constitute 5-10%, whereas the remaining scopes of depths, i.e. 20-30 m and 30-40 m constitute only ca. a 10% share in all dives, as it is demonstrated in fig. 1. Due to the fact that 99% of military divers are men, the study did not implement a division with regard to sex.

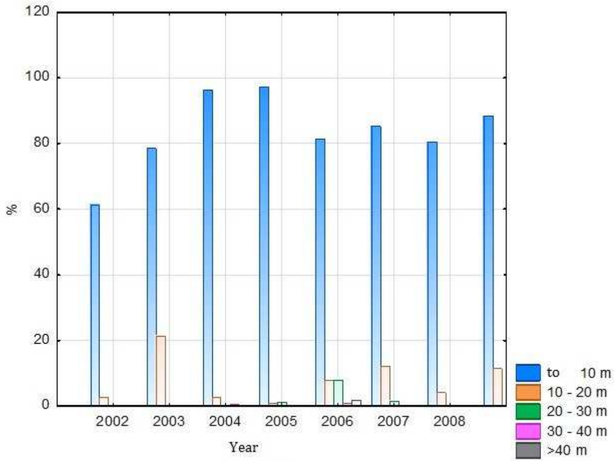

Fig. 1. The structure of diving depths realised at OSNiP WP – Source – Daily Diver Log 2001-2008; OSN i P WP].

The structure of recreational dives is quite different. Dives to the depth of up to 10 constitute only 10 –18%. The depth range of 10-20 m concerns 22 – 35% of all dives, 20-30 m – 22-30% and 30-40 m between 5 and 10%. The data indicate that recreational divers much more often penetrate the depths, while the increase in the diving depth considerably increases the risk of a diving accident. This is demonstrated on fig. 2.

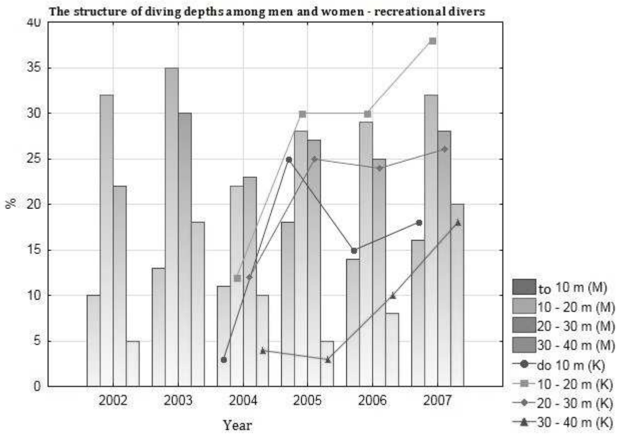

Fig. 2. The structure of diving depths realised by recreational divers from the USA and Canada – Source – Annual Diving Report 2004 – 2009; Diving Alert Network.

Diving to the depth exceeding 15 m increases the importance of factors that have a direct impact on the occurrence of typical diving-related conditions. The occurring problems are related to the observance of decompression procedure, maintenance of depth, control of diving depth and time. At greater depths, depending on the body of water, such factors include the impacts of the aquatic environment on divers, i.e. hypothermia, physical effort, i.e. a higher risk of decompression illness. It is important to note that greater depths are reached by more experienced divers, and yet they still constitute a significant hazard of accidence occurrence. The following factors and conditions influencing decompression need to be taken into account in order to ensure diving safety:

Physiological factors: sex and age, body mass, adipose tissue mass, general physical performance, special performance, level of training, cooling, overheating, past diseases and injuries, motion sickness.

Diving conditions: diving depth, time spent in overpressure, short-term, deep or saturated dives, decompression type (gradual, continuous), work in hyperbaric conditions, repeated dives, breathing mixes, oxygen during decompression, aquatic environment – currents, water temperature [8].

A crucial factor consists in monitoring the time of multilevel dives, where along with an increasing complexity of the diving profile we see a significantly elevated risk of incident occurrence.

The Spearman correlation rank allowed the observance of a statistically significant correlation between the diving depth of 30-40 m and the accident risk factor % among men with the significance level of p=0.007. Correlation coefficient is equal to R=-0.93, which constitutes a nearly complete correlation. This means that the growth in the percentage of divers at this depth lowers the risk of an accident % [2-7;]. This is demonstrated on fig. 3.

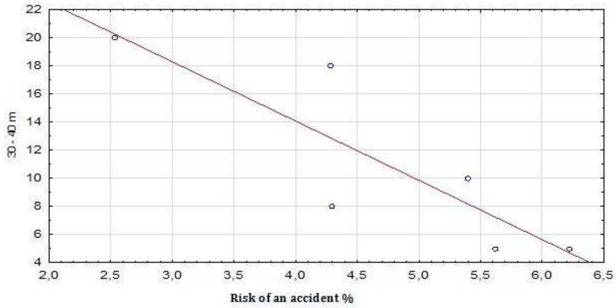

Fig. 3. Correlation between diving dept and the risk of an accident.

In the Polish Army dives are most commonly performed at the depth between 0-10 m (61 – 98% of dives). This mainly results from the task-oriented character of diving activities applied by the Armed Forces. The main objective consists in conducting training aimed at the maintenance of skills with particular emphasis on practising buoyancy in open waters, emergency procedures, modification of diving levels and control of depth, time and decompression.

Contrary to occasional recreational diving, numerous repetitions of the main elements allow to increase the level of safety of underwater works and maintain it at a good level. Also adaptation to diving may reduce decompression stress [9]. A considerably lower number of dives carried out in the depth, i.e. 10–20 m (2 – 22%) as well as at 20-30 m and 30-40 m, which do not exceed 2% of the total number of dives with sporadic strictly task-oriented dives at the depth below 40 m confirms the character of military dives [1].

Diving in the range of depths between 0 and 10 m involves numerous factors increasing the risk of an accident. Despite the fact that the said depths do not require decompression, even with relatively long stays under water the hazard of decompression sickness also exists. This concerns mainly instruction dives, the so-called yo-yo dives where during a longer period of time an instructor performs multiple submersions and ascents with different trainees. The remaining risk-enhancing factors at low depths include: the risk of pulmonary barotrauma as a result performing an ascent with a held breath, loss of ballast belt and control over buoyancy, high waves, and insufficient experience of the divers involved, multiple repeated dives and exceeding the allowable time without decompression.

The Spearman correlation rank allows the observance of a statistically significant correlation between the diving depth up to 10 m and the accident risk factor % among miliary diviers with the significance level of p=0.02. Correlation coefficient is equal to R=0.88 and constitutes a very high correlation. This means that the growth in the percentage of divers at this depth reduces the accident risk rate %. [1]. This is demonstrated on fig. 4.

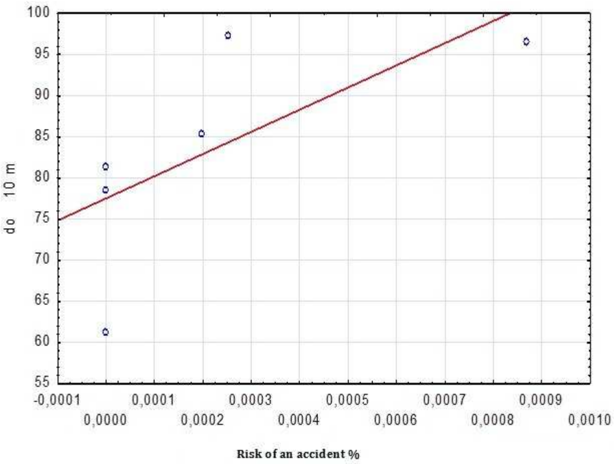

Fig. 4. Correlation between diving depth up to 10 m and the risk of a diving accident in the Polish Army.

Planning decompression.

The availability of computers in recreational diving and their growing use among divers in the USA and Canada constituted one of the most important factors affecting diving safety.

The thus far available methods of decompression planning, i.e. the use of decompression tables, instruction in their interpretation, or planning decompression by instructors were quickly abandoned for the benefit of diving computers, which were expected, first of all, to improve the comfort of diving by enabling the control of critical diving points, such as the time of submersion, diving profile, decompression model and the signalling of the fact of exceeding safety parameters, and in some cases also quantity of the breathing mix.

Already at the very beginning of their use computers were perceived as "infallible", with no effort dedicated to reading the part of the manual concerned with their operational limitations. The use of computers and other methods of decompression planning are presented on fig. 5.

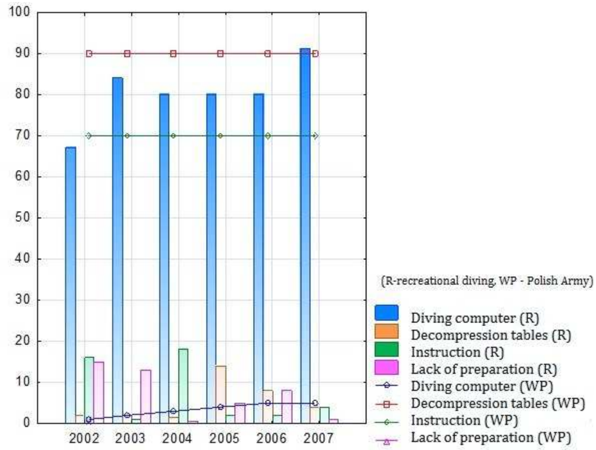

Fig. 5. Decompression planning methods – Sources – Annual Diving Report 2004 – 2009; Diving Alert Network; and Daily Diver Logs 2001-2008; OSN i P WP.

The scale of use of diving computers by recreational divers as compared with their application in the Polish Army in the discussed period is radically different. Computers were used in between 68 and 92% of recreational dives, which practically constituted the main method of decompression planning and managing the diving profile. In military use, on the other hand, this concerned only between 1 to 5% of dives.

Using decompression tables in planning decompression constituted in only 1 – 12% of cases in the community of recreational divers, while in the case of divers of the Armed Forces it was the primary method of decompression planning and was applied in 90% of cases. In recreational diving, decompression tables are used only in 2 – 12 % of cases, whereas instruction in 4% of cases and the absence of decompression planning in 1 – 15% of situations, which has a considerable impact on the safety level and the number of diving accidents.

With significance level of p=0.019, the correlation coefficient "r" between the use of a computer and the risk of an accident amounts to r=-0.887, which is a very strong correlation. The negative value of "r" indicates a downward trend in time. Consecutive years show a reduction in the accident risk coefficient despite the high percentage of computer use in decompression (in 2007 – 91%), which proves a "more conscious/more considerate" application of this method [2-7] or a technical evolution of this equipment towards much safer profiles. The risk of an accident with the use of a diving computer is presented on fig. 6.

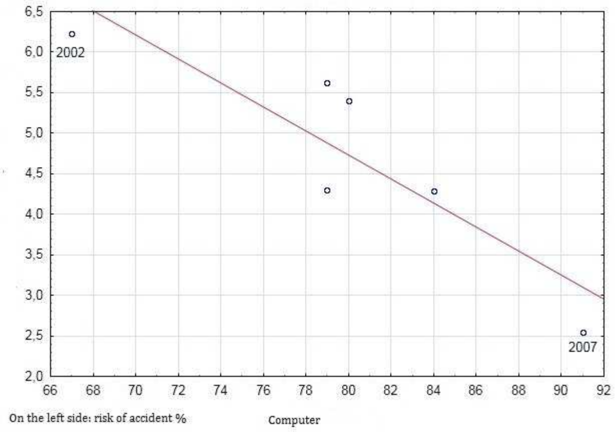

Fig. 6. The risk of a diving accident vs the use of a diving computer.

With regard to the remaining methods of decompression planning, the so-called classical decompression planning and management methods, i.e. the use of decompression tables and discussing decompression with an instructor or an experienced diver a statistically significant correlation was not observed with the accident risk coefficient.

The divers of the Armed Forces, despite the use of diving computers are obliged to be familiarised with a reserve decompression method based on decompression tables. Each dive is preceded with a detailed briefing conducted by a diving supervisor, which relates to safety conditions, equipment inspection, analysis of decompression methods and emergency procedures. In the discussed periods, there were no incidents during dives performed with a diving computer, which would have any effect on the health of divers, hence the absence of a correlation between computer use and the accident risk coefficient among the divers of the Polish Armed Forces.

A study on the structure of accidents defined by the type of dives performed showed that most commonly diving accidents occur in recreational diving, these constituting 58-75% of incidents. This result illustrates a strong correlation between freedoms of decision on the choice of diving profiles by recreational divers and lesser considerations paid to factors that have a direct effect on their safety.

A subjective assessment of one's health condition, which, despite the known or unknown health limitations the recreational divers fail to take into account, has a crucial impact on the risk and frequency of diving accidents. Candidates for recreational divers should undergo obligatory medical testing [10]; yet in the majority of countries, including Poland, health qualification is aborted under the impacts of recreation diver organisation lobbing.

A considerably lower percentage, 5-21% of accidents in training and technical dives as well as in underwater hunting shows that each organised form of diving, secured with even minimal requirements regarding the health, fitness or skills has a favourable effect on the reduction of the risk of a diving accident. A relatively low number of accidents is also observed for group dives with the presence of more experienced divers (the so-called dive masters).

The application of security measures on the surface, marking of a body of water and the use of safety ropes, improves the orientation of divers who can more easily focus on controlling the diving profile and observance of safety principles.

A large significance in the minimisation of health effects of diving accidents is the maximum shortening of the time between the accident and application of hyperbaric treatment [11], which is obtained through the use of medical assistance in the form of properly equipped first-aid kit and victim evacuation plan to a medical facility capable of ensuring proper assistance. Correlation between the number of accidents and type of underwater activity is presented on fig. 7.

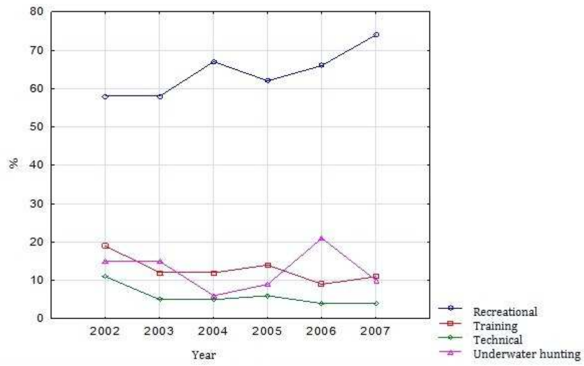

Fig. 7. Correlation between the frequency of accidents and diving type.

The significant causes of accidents (also fatal) include such factors as poor diver training, lack of experience, frequency of diving (or lack thereof), lack of competence in the use of diving equipment, lack of knowledge in diving pathophysiology and negligence of safety principles, which is illustrated in diagram 8 [2-7].

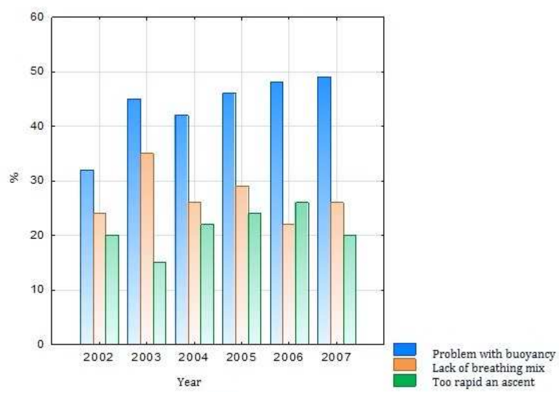

Fig. 8. Causes of fatal accidents.

The problems with buoyancy which were reported by 32-49% of recreational divers result from improper training and the infrequent character of their diving. Infrequent diving leads to a lack of habits necessary to control the diving process, from basic competences, such as control of the quantity of the breathing mix and buoyancy, through lack of orientation in open waters and not knowing how to behave in emergency situations. If this is additionally accompanied with being subject to hyperbaric conditions, the risk of an accident significantly rises.

Military divers are subject to health selection and monitoring, and, moreover, undergo continuous training with a high frequency of diving, cyclic training within the use of emergency procedures, operation of the diving equipment and implementation of procedures resulting from the diving regulations which causes them to be be exposed to the ris of occurrence of a diving incident to a much smaller degree.

The most common cause of death among recreational divers is drowning, irrespective of the initial cause of an incident. The most common reasons of death include: gas embolism, myocardial infarction/labile hypertension and decompression sickness, as causes of similar frequency of occurrence. In the researched period there were no cases of fatal accidents in the Polish Army [13], whereas in the examined group of recreational divers its number reached as many as 543. The most common diagnoses defined as the causes of death are presented on fig. 9. One should note the category of " a missing body" which usually applies to individual dives without assistance, and in particular to the so-called "technical dives".

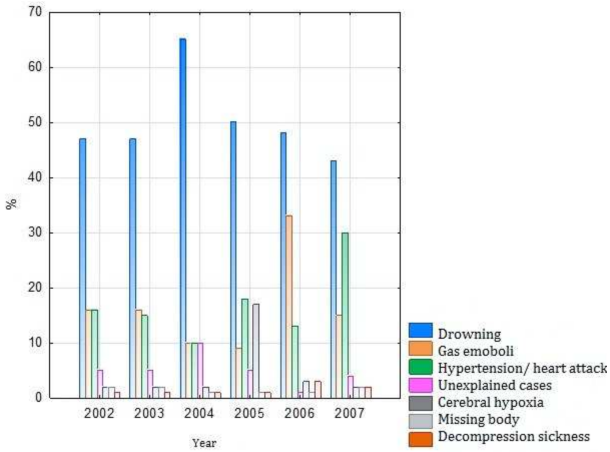

Fig. 9. Medical diagnoses of the causes of death of divers. source - Annual Diving Report 2004 – 2009; Diving Alert Network.

Diving safety can be obtained by high level training and supervision with the majority of shallow dives without decompression [14]. An important factor, accounting for the possible reasons of fatal accidents was the depth reached by the victims; which is shown in table 1.

Tab. 1.

The structure of diving depths in fatal accidents – Source – Annual Diving Report 2004 – 2009; Diving Alert Network.

Max. diving depth reached in fatal accidents	2002 %	2003 %	2004 %	2005 %	2006 %	2007 %
0-9 m	14	20	24	33	3	29
10 - 18m	29	29	25	20	13	12
19 - 27 m	16	22	29	18	20	15
28-36 m	10	22	23	20	14	14
37-45 m	10	6	25	2	12	6
46-54 m/ > 55 m	2	0	0	2/7	0/1.5	2

Military dives are usually conducted at a depth range of 0-10 m. This is mainly due to the requirements of the training programme. A large number of dives within this depth range allows for a relatively long stay underwater without the necessity to apply decompression stops and enables acquisition of the skills necessary to achieve a complete control of the diving process and equipment.

Diving at depths between 11-20 m is usually of a training or task-oriented character, i.e. they are aimed at performing a particular underwater task. Diving at depths between 21-30 m, 31-40 m and below are mainly task-oriented and require a long-standing pressure training and logistical and medical security.

The fatal recreational dives were mainly conducted at depths between 10-18 m, therefore, depending on the total diving time, they required a planned and controlled decompression procedure, which, in the absence of pressure training and the infrequency of their diving, elevated the risk of the occurrence of a diving accident. The tragic dives in the depth range between 0-9 m and 19-27 m were also characterised by a similar intensity, with the latter being much more risky. Diving accidents: barotrauma, nitrogen narcosis and decompression sickness mainly depended on depth [15].

With a common difficulty being the maintaining of buoyancy, having complete control over the diving profile and decompression procedure was certainly hard to perform during occasional dives without proper training and constituted the main factor resulting in fatal accidents. The most important individual risk factors include: diver's age, cardiological history, physical efficiency, adaptation to higher pressure conditions, diver's psychological condition [16].

A part of recreational divers as a result of diving incidents were placed in accredited centres dealing with diving-related conditions, where they were subject to complete diagnostics and treatment. The most common condition was type II decompression sickness (DCS II), which due to its course involving a number of life-threatening symptoms is an expression of a lack of preparation to perform dives.

A milder form of decompression sickness, type I (DCS I), despite a much rarer incidence, or rather ignoring of symptoms or failing to associate them with diving, confirms the existing gaps in training, disregard of safety principles and lack of knowledge of decompression rules and the common and uncritical utilisation of diving computers. Similar conclusions are drawn in relation to other diagnosed conditions.

When it comes to fatal accidents, a reliable analysis requires data concerning coexisting health conditions, data from the diving computer and specification of diving conditions [17]. Diving-related diseases and accidents recognised as causes of death are presented on fig. 10.

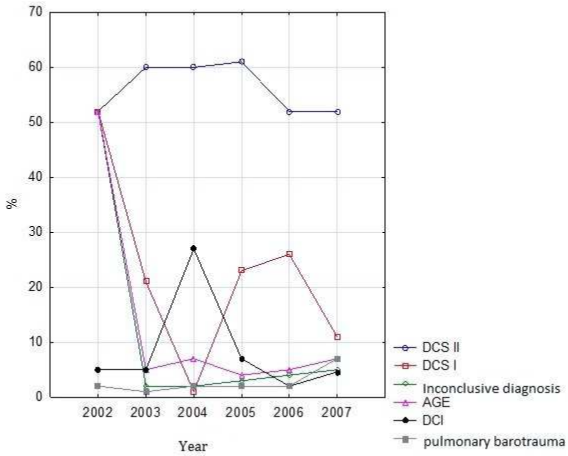

Fig. 10. Recognised diving diseases constituting causes of death – source Annual Diving Report 2004 – 2009; Diving Alert Network.

The Spearman correlation rank allowed the observance of a statistically significant correlation between decompression sickness and the percentage of fatal diving accidents with the applied significance level of p=0.034. The correlation coefficient is equal to R=0.84 and constitutes a very strong correlation. This means that the increase in the percentage of decompression sickness increases the percentage of fatal accidents. This is demonstrated on fig. 11.

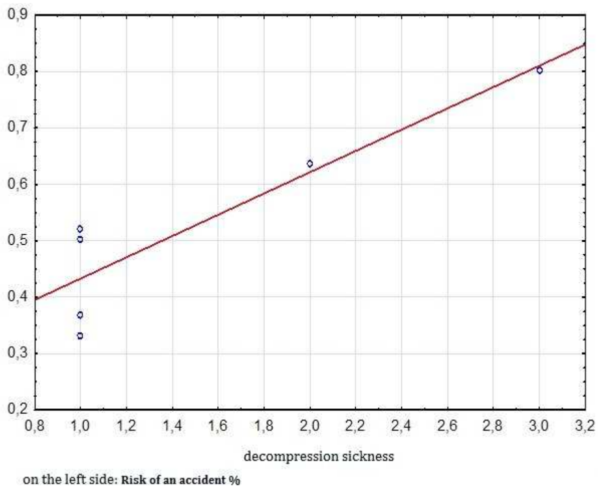

Fig. 11. The number of fatal accidents vs decompression sickness.

Both of the diagrams above illustrate the significance of the problem of decompression sickness in the diving process and a strong correlation between decompression sickness and fatal accidents among recreational divers.

Despite the use of diving computers, which were to free the divers of the risk of occurrence of decompression sickness and raise the diving safety, its incidence in correlation with the number of fatal accidents indicates that traditional diver preparation with repeated practice at small depths, instruction on diving pathophysiology, diving equipment and principles, as well as the imposition of a particular regime in the performance of suitable procedures along with the monitoring of an individual's health status significantly increases the safety of diving.

CONCLUSIONS

- The model of training in the Armed Forces of the Polish Army (pressure trainings, regular diving, and knowledge of equipment) provides a much higher guarantee of diving safety as compared with the model used in recreational diving in the USA and Canada.
- The effect of application of high regimes is the fact that in the years 2002 – 2007 no fatal accidents were noted among the military divers of the Polish Army, whereas their number among recreational divers in the USA and Canada reached 543.

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