PROGNOSTICATION OF THE RISK OF AN OCCURRENCE OF DECOMPRESSION STRESS FOLLOWING AIR DIVES

Dorota Kaczerska [1)], Katarzyna Pleskacz [2)], Piotr Siermontowski [3)]

1) Department of Clinical Nutrition, Medical University of Gdańsk, Poland
2) ITC Department, Military Institute of Medicine, Warsaw, Poland
3) Maritime and Hyperbaric Medicine Department, Military Institute of Medicine, Gdynia, Poland

ABSTRACT

The objective of the work was to investigate the impact of postprandial hypertriglyceridemia on the risk of an occurrence of decompression stress following hyperbaric air exposures. The study was conducted on 55 men aged between 20 and 48 years old (the average age 31.47±5.49 years), with a BMI value within the range of 20.3 – 33.2 kg/m^2 (25.5±2.58 kg/m^2). The participants' blood was drawn for tests 2 hours after a meal. The following parameters were defined: morphology, aspartate aminotransferase (AST) activity, alanine transaminase (ALT) activity, total cholesterol concentration and triglyceride concentration. Following each exposure, three Doppler ultrasound examinations were performed in order to determine the occurrence and intensification of decompression stress. Decompression stress was noted in 30 men. Postprandial hypertriglyceridemia and hypercholesterolemia were proven to raise the risk of occurrences of decompression stress after hyperbaric air exposures. The application of logistic regression allows a mathematical prediction of the risk associated with an occurrence of decompression stress following hyperbaric air exposures.

Key words: decompression stress, hypertriglyceridemia, diver.

ARTICLE INFO

PolHypRes 2014 Vol. 47 Issue 2 pp. 7 – 14
ISSN: 1734-7009 **eISSN:** 2084-0535
DOI: HTTP://DX.DOI.ORG/10.13006/PHR.47.1
Pages: 10, figures: 0, tables: 1.
page www of the periodical: www.phr.net.pl

Original article

Delivery date: 26.03.2014 r
Date of approval for print: 10.05.2014 r

Publisher
Polish Hyperbaric Medicine and Technology Society

INTRODUCTION

In the course of diving, inert gases in bodily fluids and tissues are subject to compression and physical dissolution. The quantity of the dissolved gas is determined by the depth and duration of a dive and the process of decompression should ensure safe physiological disposal of excess gas from an organism. However, it should be stressed that each pressure decrease, even those carried out in accordance with the decompression principles, upsets the balance between the gas – liquid phases, which facilitates the production of gas bubbles in bodily fluids and tissues. Incorrect decompression impedes the disposal of excess gas, thus increasing the risk of an occurrence of decompression sickness [1, 2].

Decompression stress consists in the occurrence of symptomless gas bubbles in the blood following a hyperbaric exposure. Although they are not always associated with an onset of the decompression sickness (DCS), their presence is not entirely neutral to the organism.

Besides the possibility of occurrence of gas emboli, i.e. a purely mechanical effect, gas bubbles constitute a foreign body in the blood circulation and induce various reactions at the transition between the liquid and gas phases.

What happens consists in the flattening of the gas bubbles with blood platelets and production of microclots that remain in the circulatory system even after bubble elimination. For this reason, the risk of an occurrence of microemboli, especially in pulmonary circulation, is considerable.

The larger the number and size of the bubbles, the more intense their activity as a foreign body, which when accompanied by repeated exposures, causes an intensification of such an effect. The scanty bubbles, flattened with microclots or the microclots themselves, may clog capillary or precapillary vessels, which on a single occasion does not produce any visible symptoms or pathological changes.

However, numerous episodes of microclotting cause damage to tissues particularly sensitive to hypoxia. During decompression, damage to adipose tissue is possible through the release of lipids or entire adipocites into the blood circulation, thus enhancing the gas embolism with fat embolism. In this case, recompression treatment fails to accomplish the expected therapeutic results [3 - 13].

Obesity is seen as a significant risk factor related to decompression sickness due to a larger storage of inert gases by tissues containing fats. Nitrogen solubility in fats is 5.2 times higher as compared with hydrated tissues.

An additional predisposing anatomic factor consists of poor vascularisation of adipose tissues, which decelerates the elimination of inert gases as opposed to hydrated tissues. It is believed that being overweight increases the statistical hazard of decompression sickness [14, 15].

Apart from the adipose tissue that may increase the volume of the dissolved inert gas during compression, it is necessary to take into account the fats circulating with the blood, which also augment solubility properties of inert gases. Due to the long duration of fat metabolism, a high-fat diet (especially in relation to meals consumed directly prior to a hyperbaric exposure) will result in a considerable increase in postprandial triglyceride level in the blood serum [16, 17, 18]. Consequently, a high-fat diet may constitute an additional risk factor by elevating the quantity of inert gas dissolved in the blood and the probability of occurrence of decompression stress (DSC).

OBJECTIVE OF THE WORK

The purpose of the work was to evaluate the effect of postprandial hypertriglyceridemia on the risk of an occurrence of decompression stress in men following hyperbaric air exposures, performed with the use of Doppler ultrasound examination.

MATERIAL AND METHOD

The study was conducted on 55 men aged between 20 and 48 years (mean age 31.47±5.49 years), with a BMI value within the range of 20.3 – 33.2kg/m2 (mean value 25.5±2.58 kg/m2). The participants' blood was drawn for tests 2 hours after a meal (breakfast) prepared in accordance with their nutritional preferences. The following parameters were defined: morphology, aspartate aminotransfe-rase (AST) activity, alanine transaminase (ALT) activity, total cholesterol concentration and triglyceride concentration.

The study was conducted by a certified laboratory for medical analyses on the day of sample collection. Next, the participants were subjected to a hyperbaric exposure corresponding to the depth of 30 m. After exposure completion, three Doppler auscultations were performed with a Doppler Bubble Monitor – DBM 9008, manufactured by the TSI Company. Following a 24-hour break the procedure was repeated: the blood samples were collected for laboratory analyses 2 hours after the meal and then the participants were subjected to a hyperbaric exposure corresponding to the depth of 60 m. On exposure completion three Doppler auscultations were performed.

The obtained results were submitted for a statistical analysis. Due to the fact that the data were not regularly distributed, non-parametric tests were applied: the Mann-Whitney U test, Spearman's rank correlation and logistic regression. The adopted level of statistical significance was $p<0.05$.

RESULTS

In the course of the exposure correspondent to the depth of 30 m, decompression stress was not observed in any of the subjects. Thus, the analysis was carried out on the results obtained during the exposure corresponding to the depth of 60 m, with regard to their impact on the occurrence of decompression stress. On the basis of the results obtained with the Doppler method, the subjects were divided into two groups: group 1 (n=25) – "stress did not occur" – no observable gas bubbles and graded as the 1st degree on the K-M scale, group 2 (n=30) – "stress occurred" – decompression stress of the 2nd – 4th degree on the K-M scale. The results are presented in Table 1.

Tab. 1.

Mean values of the measured parameters in group 1 (n=25) "stress did not occur" and in group 2 (n=30) "stress occurred".

Parameters	Mean±SD Group 1	Mean±SD Group 2	Significance level P
Age (years)	30.48±5.51	32.47±5.48	0.17
BMI [kg/m²]	24.40±1.99	26.71±3.17	0.0024
Hematocrit [%]	43.92±2.22	44.18±1.44	0.81
Hemoglobin [g/dl]	15.06±0.98	15.30±0.65	0.44
Erythrocytes [T/l]	5.07±0.29	5.00±0.33	0.41
Leucocytes [G/l]	6.65±1.87	6.84±1.98	0.6
AST [U/l]	25.44±5.07	26.63±6.98	0.7
ALT [U/l]	25.44±7.32	38.10±16.09	0.0003
Cholesterol [mg/dl]	176.44±31.83	218.07±35.12	0.00009
Triglycerides [mg/dl]	129.32±69.67	257.80±132.87	0.00004

The presented results (tab. 1) point to differences between the group of persons with decompression stress (group 2) and those in whom the decompression stress was not observed (group 1). Statistical significance ($p< 0.05$) with regard to the occurrence of stress was correlated with elevated values of BMI, ALT, total cholesterol and triglycerides. The remaining parameters were not statistically significant.

For the purpose of checking whether there was a correlation between the occurrence of decompression stress and statistically significant parameters, logistic regression was applied. Logistic regression is a mathematical model used in the description of the impact of several quantitative variables on a dichotomous variable (the fact of stress occurrence/non-occurrence).

Next, Spearman's rank correlation analysis was conducted. In order to ensure accuracy of the analytical results, collinearity and too closely correlated variables were avoided. The application of logistic regression allowed mathematical calculation of the probability of an occurrence of decompression stress depending on the values of statistically significant parameters of an examined group. The following 2 models were investigated, taking into account the measured parameters:

Model 1. ALT and triglycerides

On the basis of the results obtained through logistic regression we may determine that ALT and triglyceride levels are statistically significant ($p<0.05$) for the occurrence of decompression stress in the tested group of divers.

The calculated values allow to write down the logistic regression equation in the following form:

$$P(X) = \frac{e^{-8.56+0.18\times ALT+0.02\times TRIGLYCERIDES}}{1+e^{-8.56+0.18\times ALT+0.02\times TRIGLYCERIDES}}$$

Positive coefficients with the variables indicate that a growth in those values causes an increase in the probability of an occurrence of decompression stress.

Based on the odds ratio for the ALT variable (a unit odds ratio for the ALT variable amounts to 1.2) it is possible to calculate that persons for whom ALT reaches 38.2 U/l (mean value for persons displaying decompression stress symptoms) are 10.13 times more susceptible to decompression stress as compared with persons in whom the ALT amounted to 25.4 U/l (mean value for subjects without decompression stress).

Based on the odds ratio for the triglyceride variable (a unit odds ratio amounts to 1.02) it is possible to calculate that persons for whom triglycerides reached 257.8 mg/dl (mean value for persons displaying decompression stress symptoms) are 12.73 times more susceptible to decompression stress as compared with persons in whom the triglycerides amounted to 129.32 mg/dl (mean value for subjects without decompression stress).

Model 2. ALT – cholesterol

On the basis of the results obtained through logistic regression analysis we may determine that the levels of the ALT and cholesterol variables are statistically significant ($p<0.05$) for the occurrence of decompression stress in the tested group of divers.

The calculated values allow to write down the logistic regression equation in the following form:

$$P(X) = \frac{e^{-11.2951+0.1280883\times ALT+0.03884439\times CHOLESTEROL}}{1+e^{-11.2951+0.1280883\times ALT+0.03884439\times CHOLESTEROL}}$$

Positive coefficients with the variables indicate that a growth in those values causes an increase in the probability of an occurrence of decompression stress.

Based on the odds ratio for the ALT variable it is possible to calculate that persons for whom ALT reaches 38.1 U/l (mean value for persons displaying decompression stress symptoms) are 5 times more susceptible to decompression stress as compared with persons in whom the ALT amounted to 25.4 U/l (mean value for subjects without decompression stress).

Based on the odds ratio for the cholesterol variable it is possible to calculate that persons for whom cholesterol reached 218.7 mg/dl (mean value for persons displaying decompression stress symptoms) are 5.43 times more susceptible to decompression stress as compared with persons in whom cholesterol reached the level of 176.4 mg/dl (mean value for subjects without decompression stress).

Both of the logistic regression models indicate a greater probability of an occurrence of decompression stress in individuals whose ALT activity, cholesterol and triglyceride concentra-tions are above the norm.

DISCUSSION

The conducted study has revealed a potential impact of the thus far omitted parameters on the risk of decompression stress occurrence. The possibility to determine those parameters by each person that takes an interest in diving, and the awareness of risks related to their levels, may contribute to increasing the safety of diving, as such tests are performed as a part of a standard procedure in every medical laboratory. In the conducted research particular attention was paid to the relationship between the postprandial total cholesterol and triglyceride concentrations in the blood serum and the occurrence of decompression stress.

The fact of an elevated nitrogen solubility in the blood with considerably increased cholesterol and triglyceride concen-trations, as well as that the fats suspended in the blood plasma (chylomicrons) create a sort of a nitrogen reservoir, may provide topic for further discussions and studies on the modification of the existing decompression tables and decompression safety conditions [19, 20, 21].

The dependency between total cholesterol and triglyceride concentrations in the blood serum and the quantity of fat intake with one's diet may have a direct impact on increasing the volume of the dissolved inert gases in the blood serum during hyperbaric exposures [20]. Moreover, the functioning of the liver may have an influence on the disturbance of lipid metabolism. A growth in ALT activity is an exponent of liver cell damage, which may affect the process of cholesterol and triglyceride synthesis and result in irregular lipid metabolism [22]. The increased volume of inert gas in the blood serum will most likely be accompanied with disturbances in desaturation and delays in the transportation through the blood – air barrier [13, 23].

As it was shown by the conducted tests, an increased concentration of cholesterol and triglycerides in the blood measured 2 hours after a meal had a statistically significant impact on the risk of occurrence of decompression stress. The triglyceride concentration proved to be a particularly important prognostic parameter, since, as it follows from the presented logistic regression equation, it may increase the risk of an occurrence of decompression stress even by 12 times. Besides this, other parametric values increased above reference levels (ALT, cholesterol), having a significant impact on the occurrence of decompression stress, combined with elevated triglyceride levels, the so-called concurrence of various risk factors, increase the risk of an occurrence and intensify the stress level.

An analysis of the obtained results points to a large prognostic meaning of the above-mentioned parameters in the elimination of health hazards in divers, especially when considered collectively. Focusing on a single parameter may result in erroneous result interpretation and formulation of the wrong conclusions.

In the light of the conducted research and the data provided by the available literature it is possible to note a much larger risk of decompression stress and/or decompression sickness due to postprandial hypertriglyceri-demia. With regard to the broad spectrum of hypertriglyceridemia's effects on a human organism, and in particular on divers, as well as to the diversity of reasons for its occurrence, proper attention should be paid to such biological factors as genetic burden, environmental conditions, physical activity and diet. Diver's diet is the thus far highly underestimated risk factor, although the conducted experiment indicates its significant impact on diving-related health hazards [20].

At present, ever increasing attention is paid to the influence of a diet on the occurrence of metabolic syndrome and the related complications in the general population; however, the research concerned with persons working in extreme conditions is still in short supply. This results from the fact that people working in extreme conditions, including divers, are healthy persons of a high physical activity and commonly characterised by normal body weight. However, due to the lack of guidelines pertaining to healthy diet, such people often unknowingly make basic mistakes in this area. The awareness of threats as well as the means to increase safety may have a favourable effect on one's modification of nutritional habits. Hence, it is necessary to formulate recommendations concerned with the diet with consideration of diving-related health hazards.

CONCLUSIONS

1)Knowledge of the cholesterol, triglyceride and ALT values allows mathematic prognostication of the risk of occurrence of decompression stress in men aged between 20 – 48 years following multiple deep air dives.

2)Postprandial hypertriglyceridemia and hypercholesterolemia were proved to raise the risk of an occurrence of decompression stress after hyperbaric air exposures.

3)A constant nutritional education and preparation of proper guidelines regarding the diver's diet may have a considerable impact on decreasing the risk of an occurrence of decompression stress.

The work was carried out with the use of data analysis software "StatSoft, Inc. (2011). STATISTICA, version 10" purchased from the project entitled "TeleMedNet - medical scientific-diagnostic platform."

BIBLIOGRAPHY

1. Doboszyński T., The impact of the physical environment of the gas in hyperbaric dives in Fundamentals of Dives Pathophysiology ed. Ulewicz K. 1971: 54-71;
2. Edmonds C., Lowry Ch., Pennefather J., Physics w Diving and subaquatic medicine 1995: 11-23;
3. Bosco G., Yang Z.J., Di Tano G., et al., Effect of in-water oxygen prebreathing at different depths on decompression-induced bubble formation and platelet activation, J Appl Physiol 2010; 108 (5): 1077-1083; doi: 10.1152/japplphysiol.01058.2009;
4. Ciborowski M.F., Ruperez J., Martinez-Alcazar M.P. et al., Metabolic Approach with LC−MS Reveals Significant Effect of Pressure on Diver's Plasma, Journal of Proteome Research 2010; *9* (8): 4131-4137; doi: 10.1021/pr100331j;
5. Fothergill D.M., Gertner J., Schwaller D., Keller M., McCluskey J., Can exhaled Nitric Oxide (NO) measurements provide a non-invasive measure of decompression stress in humans?, Undersea Hyperb. Med. 2010 Sep-Oct; 37 (5) – 2010 Abstracts A4: 293;
6. Gault K.A., Tikuisis P., Nishi R.Y., Calibration of a bubble evolution model to observed bubble incidence in divers, Undersea Hyperb. Med. 1995; 22 (3): 249-262;
7. Hooker S.K., Fahlman A., Moore M.J., et al., Deadly diving? Physiological and behavioural management of decompression stress in diving mammals, Proc Biol Sci. 2012; 22, 279 (1731): 1041-1050; doi: 10.1098/rspb.2011.2088;
8. Olszański R., Radziwon P., Piszcz J. et al., Activation of platelets and fibrinolysis induced by saturated air dives, Aviation, Space and Environmental Medicine 2010; 81 (6): 585-588;
9. Olszański R., Radziwon P., Siermontowski P. et al., Trimix instead of air, decreases the effect of short-term hyperbaric exposures on platelet and fibrinolysis activation, Advances in Medical Sciences 2010; 55 (2): 313-316; doi: 10.2478/v10039-010-0050-3;
10. Pickles D.M., Ogston D., MacDonald A.G., Effects of gas bubbling and other forms of convection on platelets in vitro, J.Appl.Physiol. 1989; 67 (3): 1250-1255;
11. Pontier J.M., Gempp E., Ignatescu M., Blood platelet-derived microparticles release and bubble formation after an open-sea air dive, Appl Physiol Nutr Metab. 2012; 10.1139/h 2012-2067; doi: 10.1139/h2012-067;
12. Thom S.R., Yang M., Milovanova T.N., Decompression-induced vascular injuries are caused by micro-particles, Undersea Hyperb. Med. 2010 Sep-Oct; 37 (5) – 2010 Abstracts A5: 293;
13. Tikuisis P., Gault K., Carrod G., Maximum lekehood analysis of bubble incidence for mixed gas diving, Undersea Biomed Res 1990; 17 (2): 159-169;
14. Blatteau JE, Gempp E, Constantin P. et al. Risk factors and clinical outcome in military divers with neurological decompression sickness: influence of time to recompression. Diving Hyperb Med. 2011; 41(3): 129-34;
15. Philp RB, Gowdey CW. Experimental analysis of the relation between body fat and susceptibility to decompression sickness, Aerosp. Med. 1964; Apr,35: 351-356;
16. Goldberg A.P., Busby-Whitehead J., Katzel L.I., Krauss R.M., Lumpkin M., Hagberg J.M., Cardiovascular fitness, body composition and lipoprotein lipid metabolism in older men, J of Gerontology 2000; 55A (6): 342-349;
17. Karpe F., Steiner G., Olivecrona T., Carlson L.A., Hamsten A., Metabolism of trigliceryde-rich lipoproteins during alimentary lipemia, J Clin Invest 1993;91: 748-758;
18. Meksawan K., Pendergast D.R., Leddy J.J., Mason M., Horvath P.J., Awad A.B., Effect of low and high fat diets on nutrient intakes and selected cardiovascular risk factors in sedentary men and women, J of Am College of Nutr 2004; 23 (2): 131-140;
19. Cockett A.T.K., Pauley S.M., Saunders J.C., Hirose F.M., Co-existence of lipid and gas emboli in experimental decompression sickness, NASA Technical Reports Server 1968;
20. Kaczerska D., Siermontowski P., Olszański R., Krefft K., Małgorzewicz S., Van Damme-Ostapowicz K., The influence of high-fat diets on the occurrence of decompression stress after air dives, Undersea Hyperb. Med. 2013; 40 (6): 487-497
21. Pauley S.M., Cockett A.T.K., Role of lipids in decompression sickness, Aerospace Med 1970; 41 (1): 56-60;
22. Brunzeli J.D., Hazzard W.R., Porte D., Bierman E.L., Evidence for a common, saturable, trigliceryde removal mechanism for chylomicrons and very low density lipoproteins in man, J Clin Invest 1973; 52: 1578-1585;
23. Butler B.D., Conkin J., Luehr S., Pulmonary hemodynamics, extravascular lung water and residual gas bubbles following low dose venous gas embolism in dogs, Aviat Space Environ Med. 1989 Dec; 60 (12):1178-1182.

mgr inż.Dorota Kaczerska
Katedra Żywienia Klinicznego
Gdański Uniwersytet Medyczny
ul. Dębinki 7, 80-211 Gdańsk
dorotakaczerska@tlen.pl