Int Marit Health
2019; 70, 1: 61–64
DOI: 10.5603/IMH.2019.0009
www.intmarhealth.pl

ISSN 1641–9251

VIA MEDICA

ORIGINAL ARTICLE

Study of the changes in respiratory function in self-contained underwater breathing apparatus divers

Nikola Georgiev Shopov

Military Medical Academy, Centre of Military Medical Expertise Aero and Maritime Medicine, Varna, Bulgaria

ABSTRACT

Background: *The objective was to investigate the respiratory function of professional divers by conducting spirometry and to compare the data obtained with those of non-divers.*

Materials and methods: *This study involved 52 military divers who carried out dives at small and medium depths using a self-contained underwater breathing apparatus (SCUBA) with open-circuit regulators attached to a mouthpiece. The control group consisted of 48 persons from deck commands with similar physiological characteristics and lifestyle that were not divers and had never been under increased pressure.*

Results: *It was found that, compared with non-divers, the spirometry parameters of the divers are characterised by higher values of forced vital capacity (FVC) of the lungs ($p = 0.02$), but significantly lower values of the mid-expiratory flow (MEF) parameters: MEF_{25} ($p = 0.06$), MEF_{50} ($p = 0.04$), and MEF_{75} ($p = 0.01$), as well as for the ratio of forced expiratory volume in 1 second (FEV_1) to forced vital capacity (FEV_1/FVC; $p = 0.001$) and MEF_{25-75}/FVC ratio ($p < 0.001$).*

Conclusions: *Hyperoxia, gas decompression bubbles, hypothermia, mouth-breathing dry, cold, compressed air, and other factors accompanying the diving activity are capable of initiating damage to the airways, which is reflected in characteristic changes in spirometry. The pattern of these changes is consistent with small airway obstruction and they could be related mostly to diving activities.*

(Int Marit Health 2019; 70, 1: 61–64)

Key words: spirometry of divers, airway injuries in divers, respiratory function

INTRODUCTION

Divers working on small and medium depths represent the main group of the representatives of this profession; however, the nature of functional changes in their organisms, including those involving the respiratory system, have not been clearly explained. Diving is a strenuous underwater activity in which environmental conditions affect the functions and structure of tissues. Of all body systems, the respiratory system is the most affected by diving, and from this point of view, pulmonary function test of the divers can give us valuable information about the consequences of this activity.

Early studies in commercial offshore divers [1] and one study in recreational self-contained underwater breathing apparatus (SCUBA) divers [2] indicated an accelerated loss of forced vital capacity (FVC) over time that was associated with diving exposure. Long-term effects on respiratory function have been found in commercial divers who perform deep dives [3]. In contrast to these results from commercial diving cohorts, more recently a number of studies in military or recreational SCUBA divers using air or nitrox reported no accelerated decline in lung function over time. A study of divers who dive in shallow water using compressed air showed lower mid-expiratory flow at 25% of vital capacity (MEF_{25}) than controls [4]. Another study at 93 United States Navy divers [5] showed higher FVC (12.2%) than predicted and forced expiratory volume in 1 second (FEV_1) 4.3% below predicted values. Years of diving was not significantly related to lung function. In a study on 120 military divers, Najim AH Alewi et al. [6] found that forced expiratory time (FET) was significantly higher in divers than in non-divers. All other pulmonary function tests were found to be lower in divers as compared with non-divers.

Associate Professor Nikola Georgiev Shopov, Military Medical Academy, Centre of Military Medical Expertise Aero and Maritime Medicine, 3, Hristo Smirnenski Str., 9000 Varna, Bulgaria, e-mail: shopov@vma.bg

Table 1. Comparison of physiological characteristics of diving group and controls

Parameters	Age [years]	Height [cm]	Weight [kg]	BMI [kg/m^2]	Atopics [%]	Smokers [%]	Smoking index
Divers	35.20 ± 10.050	178.50 ± 8.250	84.30 ± 11.045	25.80 ± 4.600	19.60	25.00	14 (10–21)
Controls	36.40 ± 11.025	177.50 ± 6.750	82.40 ± 10.175	25.70 ± 4.400	18.75	22.92	8 (9–12)
P	NS	NS	NS	NS	NS	NS	NS

Values are means ± standard deviation; only values of smoking index are medians with range. Differences were considered statistically significant at $p < 0.05$. BMI — body mass index; NS — not significant

It can be said that the results of the various studies assessing the consequences of regular underwater dives are contradictory. The influences reported range from insignificant [7] to substantial [8]. The published studies usually include a small number of subjects and are relatively underpowered, so it is necessary to conduct more observational studies to determine the impact of the diving activity on the diver's respiratory function.

The purpose of this paper is to present the results of a comparative study of respiratory function of professional military divers by carrying out a spirometry and to compare the results with the data obtained in non-divers.

MATERIALS AND METHODS

The results of the study of 52 military divers using SCUBA with open-circuit regulators attached to a mouthpiece were analysed. Dives were carried out in small and medium depths, using compressed air as breathing gas. The control group consisted of 48 persons from deck commands with similar physiological characteristics and lifestyle who were not divers and had never been under increased pressure. The lung function was assessed with a spirometer (Cosmed-Pony FX, Italy). Measurements were performed in accordance with the recommendations of the American Thoracic Society and European Respiratory Society (ATS/ /ERS, 2005) [9]. The following indicators were analysed:
- forced vital capacity (FVC);
- forced expiratory volume in 1 second (FEV_1);
- peak expiratory flow (PEF);
- forced expiratory flow (FEF), also known as mid-expiratory flow (MEF); the rates at 25%, 50% and 75% FVC;
- forced expiratory flow between 25% and 75% ($FEF_{25–75}$), $MEF_{25–75}$;
- FEV_1/FVC ratio, also called Tiffeneau-Pinelli index;
- $FEF_{25–75}$/FVC ratio.

We took into account the smoking rates among the divers, because it is a proven risk factor of developing chronic obstructive pulmonary disease (COPD) [10]. The smoking index is an empirically established indicator that shows the relationship between smoking rates and the likelihood of developing COPD. It is calculated by multiplying the number of cigarettes smoked per day by the smoking years and dividing the resulting number to 20. If the smoking index is higher than 10, there is a high risk of developing COPD.

The statistical analysis was performed using the IBM SPSS Statistics Version 25 software package. The characteristics of the groups are presented as means values standard deviation (M ± SD).

The total length of service of the divers was 10.2 ± 2.500 (range 5–16) years. Underwater experience: the total number of hours under water was 2028.50 ± 358.750 (range 500–3500), average depth of dives was 13.75 ± 0.575 (range 12–16) metres, and maximum depth of dives was 39.50 ± 8.250 (range 30–60) metres.

The study groups were not statistically significantly different in age, height, body weight, percentage of smokers and the smoking index, or the proportion of subjects with a history of atopy (Table 1). Differences were considered statistically significant at $p < 0.05$.

ETHICAL CONSIDERATIONS

Throughout the research processes we have observed the ethical principles for medical research involving human subjects of the Declaration of Helsinki.

RESULTS

The absolute values of spirometry parameters of divers and the control group are presented in Table 2. The parameters in percentage of the predicted values are presented in Table 3.

For 3 divers Tiffeneau's index did not reach 70%, although they showed FEV_1 values above 100% of the predicted values. These divers underwent additional medical tests to reject the presence of bronchial obstruction. There were no such cases in the control group.

DISCUSSION

Forced vital capacity, expressed both in absolute values and in percentage of predicted values, was higher for the divers compared to controls. Differences in volume parameters (FEV_1 and PEF) were not found, but the other flow parameters (MEF_{50}, MEF_{25}, $FEF_{25–75}$) were higher in subjects in the control group. Also, the FEV_1/FVC and $FEF_{25–75}$/FVC ratios were higher in the control group. Recent research

Table 2. Values of the parameters of the divers and the control group

Parameters	Divers	Control group	p
FVC [L]	5.7 ± 0.820	5.3 ± 0.710	0.02
FEV_1 [L]	4.3 ± 0.630	4.3 ± 0.705	NS
PEF [L/s]	10.0 ± 1.840	9.9 ± 1.720	NS
MEF_{75} [L/s]	7.8 ± 1.480	8.5 ± 1.620	0.05
MEF_{50} [L/s]	4.3 ± 1.280	4.9 ± 1. 320	0.04
MEF_{25} [L/s]	1.4 ± 0.560	1.8 ± 0.610	0.01
FEF_{25-75} [L/s]	3.5 ± 0.950	4.0 ± 1.050	0.01
FEV_1/FVC	0.78 ± 0.060	0.82 ± 0.040	0.002
FEF_{25-75}/FVC	0.66 ± 0.190	0.80 ± 0.160	0.001

Values are means ± standard deviation. Differences were considered statistically significant at $p < 0.05$; NS — not significant; FVC — forced vital capacity; FEV_1 — forced expiratory volume in 1 second; PEF — peak expiratory flow; MEF — mid-expiratory flow; FEF — forced expiratory flow; FEF_{25-75} — forced expiratory flow between 25% and 75%

Table 3. Values of the parameters of the divers and the control group in percentage of the predicted values

Parameters	Divers, % of predicted	Control group, % of predicted	p
FVC [L]	113.2 ± 16.110	105.6 ± 9.050	0.03
FEV_1 [L]	105.3 ± 13.960	105.8 ± 11.870	NS
PEF [L/s]	107.1 ± 11.750	102.9 ± 10.660	NS
MEF_{75} [L/s]	98.5 ± 14.120	102.0 ± 13.640	NS
MEF_{50} [L/s]	83.4 ± 9.650	93.4 ± 10.110	0.04
MEF_{25} [L/s]	58.2 ± 8.780	75.7 ± 9.020	0.002
FEF_{25-75} [L/s]	77.4 ± 10.980	87.4 ± 11.450	0.02

Values are means ± standard deviation. Differences were considered statistically significant at $p < 0.05$; NS — not significant; FVC — forced vital capacity; FEV_1 — forced expiratory volume in 1 second; PEF — peak expiratory flow; MEF — mid-expiratory flow; FEF — forced expiratory flow; FEF_{25-75} — forced expiratory flow between 25% and 75%

suggests that FEF_{25-75} or FEF_{25-50} may be a more sensitive parameter than FEV_1 in the detection of obstructive small airway disease [11, 12]. The data we have obtained show similar results.

There are many factors accompanying diving that are capable of causing an adverse effect on the respiratory system and numerous physical and chemical changes. Stringent medical requirements for the health of military divers lead to better functional reserves and adaptive capabilities of this category of persons. On the other hand, higher environmental pressures, higher density of breathing mixture, hyperoxia, and decompression stress are most important factors. Moreover, diving is associated with development of early airway hyperresponsiveness in atopic subjects [13]. Under the influence of these stressors there are significant changes in the mechanics of breathing, pulmonary circulation and the respiratory drive, aimed at maintaining an adequate gas exchange under hyperbaric conditions.

Frequent diving can result in persistent long-term changes from the respiratory organs [14]. The results of various studies on the impact of regular underwater diving are controversial. Skogstad suggest that diving has contributed to the reduction in lung function [15]. However, the analysis of literature data suggests that professional divers may notice certain changes in external breathing, which result in an increase in static pulmonary volumes and a moderate reduction in forced expiratory volumes [8, 14]. We found a small increase in the FVC without a proportional increase in the speed indicators ($MEF_{25, 50, 75}$ and FEF_{25-75}).

The causes and mechanisms of development of the described changes, as well as their physiological significance, remain unclear. The obstructive type of imbalance between vital capacity and FEV_1 can be determined by the inborn characteristics of the divers, as well as unfavourable environmental factors. Some studies have demonstrated that these changes are associated with bronchial hyperreactivity and are likely to play a role in the development of bronchial asthma and COPD [16].

The hyperoxia, decompression gas bubbles, hypothermia, which accompanies diving activity are able to initiate damage of the airways and pulmonary parenchyma. When using an open-circuit diving regulators, the mouth-breathing of dry, cold, compressed air can irritate the airways and provoke further damage of the airway epithelium and changes in airway wall structure and function [17]. An increase in bronchial susceptibility to bronchoconstrictive factors during diving [13], as well as the rapid rate of decrease in FEV_1 and FEF_{25-75} in divers, also shown in dynamic observation [15], confirm these findings.

CONCLUSIONS

Hyperoxia, gas decompression bubbles, hypothermia, mouth-breathing of dry, cold, compressed air, and other factors accompanying the diving activity are capable of initiating damage to the airways, which is reflected in characteristic changes in spirometry. The pattern of these changes is consistent with small airway obstruction and they could be related mostly to diving activities.

REFERENCES

1. Watt SJ. Effect of commercial diving on ventilatory function. Br J Ind Med. 1985; 42(1): 59–62, indexed in Pubmed: 3965017.
2. Wilson A. Prevalence and characteristics of lung function changes in recreational scuba divers. Prim Care Respir J. 2011; 20(1): 59–63, doi:10.4104/pcrj.2010.00063, indexed in Pubmed: 21085916.
3. Elliott DH, Moon RE. Long-term health effects of diving. In: Bennett PB (eds.) The Physiology and Medicine of Diving. 4th Edn. London, Saunders. 1993: 585–604.
4. Tetzlaff K, Friege L, Reuter M, et al. Expiratory flow limitation in compressed air divers and oxygen divers. Eur Respiratory J. 1998; 12(4): 895–899, doi:10.1183/09031936.98.12040895.
5. Dembert ML, Beck GJ, Jekel JF, et al. Relations of smoking and diving experience to pulmonary function among U.S. Navy divers. Undersea Biomed Res. 1984; 11(3): 299–304, indexed in Pubmed: 6506340.
6. Najim AH Alewi, Jasim N. Al-Asadi, Omran S. Habib. The effects of diving on pulmonary function. The Medical Journal of Basrah University. 2006; 24(18.2): 55–59.
7. Sames C, Gorman DF, Mitchell SJ, et al. The long-term effects of compressed gas diving on lung function in New Zealand occupational divers: a retrospective analysis. Diving Hyperb Med. 2009; 39(3): 133–137, indexed in Pubmed: 22753243.
8. Crosbie WA, Reed JW, Clarke MC. Functional characteristics of the large lungs found in commercial divers. J Applied Physiology. 1979; 46(4): 639–645, doi: 10.1152/jappl.1979.46.4.639.
9. Miller MR, Hankinson J, Brusasco V, et al. ATS/ERS Task Force. Standardisation of spirometry. Eur Respir J. 2005; 26(2): 319–338, doi: 10.1183/09031936.05.00034805, indexed in Pubmed: 16055882.
10. Stang P, Lydick E, Silberman C, et al. The prevalence of COPD: using smoking rates to estimate disease frequency in the general population. Chest. 2000; 117(5, Suppl. 2): 354S–359S, doi: 10.1378/chest.117.5_suppl_2.354S.
11. Simon MR, Chinchilli VM, Phillips BR, et al. Forced expiratory flow between 25% and 75% of vital capacity and FEV1/forced vital capacity ratio in relation to clinical and physiological parameters in asthmatic children with normal FEV1 values. J Allergy Clin Immunol. 2010; 126(3): 527–534.e1, doi:10.1016/j.jaci.2010.05.016, indexed in Pubmed: 20638110.
12. Ciprandi G, Cirillo I. Forced expiratory flow between 25% and 75% of vital capacity may be a marker of bronchial impairment in allergic rhinitis. J Allergy Clin Immunol. 2011; 127(2): 549; discussion 550–549; discussion 551, doi: 10.1016/j.jaci.2010.10.053, indexed in Pubmed: 21281879.
13. Cirillo I, Vizzaccaro A, Crimi E. Airway reactivity and diving in healthy and atopic subjects. Med Sci Sports Exerc. 2003; 35(9): 1493––1498, doi:10.1249/01.mss.0000084424.67486.5b.
14. Macdiarmid JI. at al. Co-ordinated investigation into the possible long term health effects of diving at work: Research report. Great Britain. Health and Safety Executive, Vol. 230, Sudbury: HSE Books. 2004: 105.
15. Skogstad M, Thorsen E, Haldorsen T, et al. Lung function over six years among professional divers. Occup Environ Med. 2002; 59(9): 629–633, doi:10.1136/oem.59.9.629, indexed in Pubmed: 12205238.
16. Parker AL, Abu-Hijleh M, McCool FD. Ratio between forced expiratory flow between 25% and 75% of vital capacity and FVC is a determinant of airway reactivity and sensitivity to methacholine. Chest. 2003; 124(1): 63–69, indexed in Pubmed: 12853503.
17. Heikki OK. Cold air-provoked respiratory symptoms: the mechanisms and management. Int J Circumpolar Health. 2007; 66(2): 91–100, doi:10.3402/ijch.v66i2.18237.