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The changes in pulmonary functions in occupational divers: smoking, diving experience, occupational group effects

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ABSTRACT

Background: *Diving challenges the respiratory system because of the pressure changes, breathing gases, and cardiovascular effects. We aimed to analyse the long term effect of occupational diving on pulmonary functions in terms of diving experience (year), smoking history, and occupational groups (commercial divers and SCUBA instructors).*

Materials and methods: *We retrospectively analysed respiratory system examination results of the experienced occupational divers who were admitted to the Undersea and Hyperbaric Medicine Department for periodic medical examination between January 1, 2013 and February 28, 2019.*

Results: *Sixty-four divers applied to our department. Candidate divers were not included in our study. The mean diving experience (year) was 13.6 ± 7.3. None of the divers complained of pulmonary symptoms. Pulmonary auscultation and chest radiography were normal in all cases. In divers with 20 years or more experience, the FEV1/FVC ratio and FEF25–75(%) was significantly lower ($p < 0.001$, $p < 0.05$, respectively). In addition, there was a statistically significant negative correlation between FEV1/FVC ratio and FEF25–75(%) and diving experience (year) ($p < 0.05$, $r = -0.444$, $p < 0.05$, $r = -0.300$, respectively). As the diving experience increase per 1 year, the FEF25–75(%) value decreases by 1.04% according to linear regression analyses. However, smoking and occupational groups did not show any significant influence on pulmonary function test parameters.*

Conclusions: *Occupational diving seems to create clinically asymptomatic pulmonary function test changes related to small airway obstruction after long years of exposure.*

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Key words: diving, respiratory, pulmonary function, occupational health, occupational diving, commercial divers

INTRODUCTION

The human respiratory system is not physiologically adapted to breathing underwater. However, the human race has always been pushing the limits of their physiology. Diving leads to physiologic alterations in the human body, even in the shallow water, mainly on the respiratory system [1]. While the breath-holding duration limits breath-hold diving, diving with breathing support provides longer dives and longer extreme environmental exposures. It challenges the human respiratory system due to the pressure changes, breathing different gases, altered gas characteristics, increased work of breathing, increased respiratory heat loss, and cardiovascular effects of immersion [1].

The question of interest is about the prolonged effects of diving and the possibility of persistent changes in the pulmonary functions [2]. There is more attention growing on the divers' future health impact. This interest has been supported by the workplace health and safety aspects of occupational diving [3]. Many studies have been conducted about the long term pulmonary effects of diving on commer-

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cial divers, military divers, recreational SCUBA divers, and special populations. However, the results are conflicting. Some authors report a decrease in pulmonary function, others suggesting an increase, while some reports find no difference at all [1, 2, 4–13].

Occupational divers are the main population who are exposed to a deep water environment regularly for long years. We aimed to analyse the long term effect of occupational diving on pulmonary functions in terms of diving experience (year). Also, we aimed to determine the impact of smoking consumption and the occupational groups (commercial divers and SCUBA instructors) on pulmonary functions.

MATERIALS AND METHODS

We retrospectively analysed the medical records of occupational divers who presented to Undersea and Hyperbaric Medicine Department for routine medical examination between January 1, 2013 and February 28, 2019. Occupational divers older than 18 years old were included in our study. SCUBA instructors were also accepted as occupational divers. However, occupational diver candidates without any professional diving experience, medical records with inadequate data, and military divers were excluded. The demographic data, body mass index (BMI), diving experience (years), past medical history, smoking habit, respiratory system physical examination results, radiological examination results, and pulmonary function test (PFT) results were recorded. The divers who quitted smoking for more than 1 year were defined as ex-smokers. The PFTs were completed in the same laboratory for each diver according to the recommendations of the European Respiratory Society guidelines. Functional vital capacity (FVC), forced expired volume in 1 second (FEV1), the FEV1/FVC ratio, forced expiratory flow between 25% and 75% of FVC (FEF25–75) were collected. The statistical analyses conducted with the predicted values (%) values of these parameters. As we chose to use predicted values, age, and BMI was not used as a comparison parameter for PFT results. This study was approved by the Ethical Committee of Gülhane Non-invasive Investigations (approval number = 19/309, Date = 08/10/2019).

STATISTICAL ANALYSIS

Data analysis was performed using SPSS Statistics Version 21 (IBM Corp., Armonk, NY). The data are reported as % (n) and mean ± standard deviation. Kolmogorov-Smirnov test or Shapiro-Wilk test was performed to determine the normal distribution of continuous variables. Pearson or Spearman correlation analysis was performed to analyse the linear correlation between continuous variables (PFT values, diving year, smoking consumption). Simple linear regression analysis was performed to study the effect of diving experience (year) on FEF25–75(%) value because only the FEF25–75(%) data was normally distributed and has a statistically significant linear correlation. The comparison of PFT values and occupational groups were analysed with Student t-test or Mann-Whitney U. On the other hand, ANOVA or Kruskal-Wallis was performed for the comparison between PFT values and diving experience (year) group, smoking history. The Tukey test was used for post-hoc analysis. A χ^2 test was used for the smoking habit and occupational group comparison. $P < 0.05$ was considered statistically significant.

RESULTS

Between January 1, 2013 and February 28, 2019, 64 experienced occupational divers applied to our department to obtain fitness to dive medical reports. The demographic data of the divers were analysed in Table 1. According to the World Health Organization classification, 50% of divers were overweight (BMI 25–29.9), and 12.5% were obese (BMI 30–34.9). The mean pack-years of smoking was 15.5 ± ± 18.9. None of the divers had any respiratory system-related medical condition. None of the divers complained about any related pulmonary symptoms such as dyspnoea, or cough. Pulmonary auscultation and chest radiography were normal in all of the divers.

The comparison of demographic data and PFT results according to the occupational group is available in Table 1. While both diver groups were demographically similar, there wasn't any statistically significant difference for none of the PFT parameters (Table 1).

The relationship between each PFT parameter and the smoking habit was analysed. Only the FEV1/FVC results didn't fit normal distribution according to the Kolmogorov-Smirnov test among all PFT parameters. There was not any statistically significant difference for any PFT value between active smokers, those who quit smoking, and those who never smoked (Table 2).

The effect of diving experience (year) on PFT values were studied. Diving experience was classified as three groups; 0–9 years (n = 14), 10–19 years (n = 23) and ≥ 20 years (n = 10) experience. The FEV1/FVC ratio and FEF25–75(%) values in divers with ≥ 20 years diving experience were found to be statistically significantly lower than both of the other groups ($p < 0.001$, $p < 0.05$, respectively; Fig. 1).

The correlation between the diving experience (year), smoking consumption (package/year), and PFT values were studied. There was a statistically significant moderate negative correlation between the diving experience (year) and the FEV1/FVC ratio ($p < 0.05$, $r = -0.444$), according to Spearman correlation analysis. Similarly, there was a statistically moderate negative correlation between diving year

Table 1. The comparison of demographic data and pulmonary function test parameters among commercial divers and SCUBA instructors (Student t-test, Chi-square, and Mann-Whitney U were used)

	Total population Mean (SD) or n (%)	**SCUBA instructors Mean (SD) or n (%)**	**Commercial divers Mean (SD) or n (%)**	**P-value**
Age [years]	43.7 (10.6)	45 (9.9)	39.4 (11.5)	0.070
BMI [kg/m^2]	26 (3)	25.9 (3.1)	26.4 (2.9)	0.558
Smoking habit				0.087
Active smokers	20 (31.3%)	17 (34.7%)	3 (20%)	
Ex-smokers	10 (15.6%)	5 (10.2%)	5 (33.3%)	
Never-smokers	34 (53.1%)	27 (55.1%)	7 (46.7%)	
Diving experience (year)	13.6 (7.3)	13.4 (7.3)	14.1 (7.7)	0.779
PFT parameters				
FEV1 (%)	106.212.7)	106.8 (13.4)	104.2 (10.1)	0.283
FVC (%)	105.1 (10.7)	105.9 (11.1)	102.5 (9.7)	0.500
FEV1/FVC (%)	102.1 (11.3)	101.6 (10.6)	103.7 (13.5)	0.421
FEF25–75 (%)	99.7 (24.7)	98.6 (25.4)	102.9 (23.1)	0.566
PEF (%)	109.2 (18)	108.8 (18.8)	110.5 (15.9)	0.746

SD —standard deviation; BMI — body mass index; FVC — functional vital capacity; FEV1 — forced expired volume in 1 second; FEF25–75 — forced expiratory flow between 25% and 75% of FVC; PEF — peak expiratory flow

Table 2. The pulmonary function test (PFT) values for total population and the detailed PFT analyses due to smoking habits (ANOVA and Kruskal-Wallis)

	Smoking habit — mean (standard deviation)			
	Active smokers (n = 20)	**Ex-smokers (n = 10)**	**Never-smokers (n = 34)**	**P-value**
FEV1 (%)	102 (12.4)	109.7 (17.9)	107.5 (10.7)	0.194
FVC (%)	101.5 (9.8)	111.2 (12.3)	105.5 (10.2)	0.065
FEV1/FVC (%)	102.2 (11.8)	99.5 (13.8)	102.7 (10.3)	0.916
FEF25–75 (%)	91.7 (27.6)	102.2 (33.1)	103.2 (19.5)	0.268
PEF (%)	107.9 (22.1)	108.4 (11.8)	110.0 (17.6)	0.917

FVC — functional vital capacity; FEV1 — forced expired volume in 1 second; FEF25–75 — forced expiratory flow between 25% and 75% of FVC; PEF — peak expiratory flow

and FEF25–75(%) ($p < 0.05$, $r = -0.300$), according to the Pearson correlation analysis. Similarly, there was no statistically significant correlation between smoking history (for active smokers) and any PFT parameter due to correlation analyses (Table 3).

Linear regression analysis was performed between the diving experience (year) and FEF25–75(%). The regression equation was found to be statistically significant ($R^2 = 0.90$, $F_{1,43} = 4.244$, $p < 0.05$). According to this analysis, as the diving experience increase per 1 year, FEF25–75(%) value decreases by 1.04%.

DISCUSSION

In this study, we analysed the effects of diving year, smoking, and occupational groups on experienced professional divers' pulmonary functions. We found that FEV1/FVC(%) and FEF25–75(%) are statistically significantly lower among divers who had 20 years or more diving experience ($p < 0.001$, $p < 0.05$, respectively) Additionally, FEV1/FVC(%) and diving experience (year) had a statistically significant moderate negative correlation ($p < 0.05$, $r = -0.443$). Similarly, there was a statistically moderate negative correlation between diving year and FEF25–75(%) ($p < 0.05$, $r = -0.300$). According to the linear regression analysis, as the diving experience increase per 1 year, FEF25–75(%) value decreases by 1.04%. On the other hand, smoking and occupational groups did not show any significant influence on PFT parameters.

Cigarette smoking is known as a risk factor affecting respiration and oxygen delivery. It is related to a reduction in respiratory volumes. Ergun et al. [14] found that current smokers have lower FEV1(%) and FVC(%) levels than never smokers in a healthy normal population without chronic obstructive pulmonary disease. The smoking effect has also been questioned in divers. Sekulic and Tocilj [15] conducted a study about the relationship between smoking and PFT results on 57 military divers. There was not any statistically significant relation between smoking status and PFT values. The authors concluded that in military divers, respiratory muscle training might partially offset the negative effect of smoking on PFTs [15]. Similarly, Chong et al. [16] and Sames et al. [13] did not find any relation between PFT values and smoking history in occupational divers. The active smokers' ratio was 31.3% (n = 20) in our study, which is relatively higher than worldwide smoking prevalence (20.4%) and our national smoking prevalence (27.2%) in 2016 [17]. Although our smoking ratio was higher than both the worldwide and the national smoking ratio, we also have not found any statistically significant relationship between smoking habits and PFT values. The physical training effect may be beneficial for lessening the smoking effect on the lungs [15]. On the other hand, there might be a healthy worker effect in two ways. Firstly, the selected population consists of workers who have to be medically fit continuously. Secondly, divers experiencing pulmonary difficulties would quit this occupation [18].

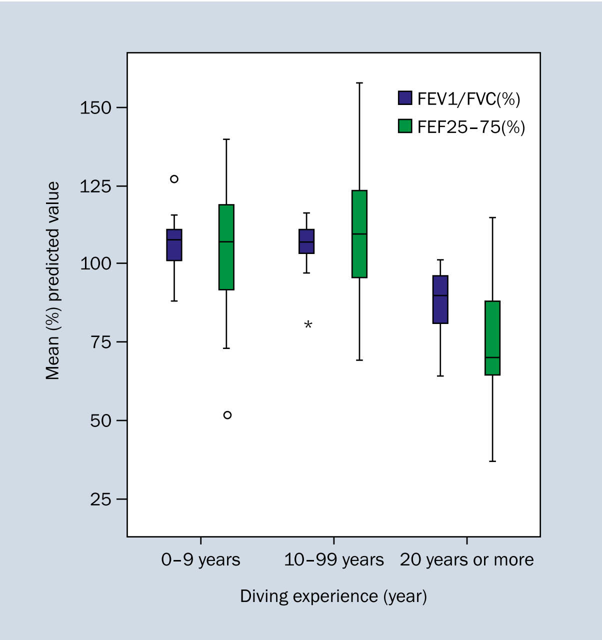

Figure 1. Comparison of FEV1/FVC and FEF25–75(%) between diving experience (years) groups (ANOVA and Kruskal-Wallis); FVC — functional vital capacity; FEV1 — forced expired volume in 1 second; FEF25–75 — forced expiratory flow between 25% and 75% of FVC

Human physiology adapts to diving exposure [1]. In this respect, mainly pulmonary functions have been studied in the diver population. The previous studies showed that divers have larger lung volumes. The most related evidence is a more significant increase in FVC than FEV1, which leads to a decrease in the FEV1/FVC ratio. This is interpreted as a natural selection of people who want to dive but also related to repetitive breath-holding and resistance for breathing during diving [19–21]. Some studies reported a reduction in expiratory flows at low pulmonary volumes, possibly due to pathological changes in the lung periphery [22]. Skogstad et al. [11] followed 69 pre-exposed divers and 18 never-exposed divers for 3 years. After this period, there was a significant decrease in the mean FEV1(%), FEF25–75(%), and FEF75(%) values. Authors concluded that diving might lead to changes in PFT, mostly affecting small airways conductance and dysfunction. Skogstad et al. [23] showed a decrease in FEF25–75(%), also after 12 years of diving. Besides, Shopov [9] studied PFT results in military divers (n = 52) and compared with a control group (n = 48) who were

Table 3. Correlation between pulmonary function test values, diving experience (year) and smoking consumption

	P-value	r value		P-value	r value
Diving year FEV1 (%)	0.625	–0.073	Smoking (pack/year) FEV1 (%)	0.274	–0.232
Diving year FVC (%)	0.065	0.271	Smoking (pack/year) FVC (%)	0.700	–0.083
Diving year FEV1/FVC (%)	0.016*	*–0.444*	Smoking (pack/year) FEV1/FVC (%)	0.167	–0.298
Diving year FEF25–75 (%)	0.045*	*–0.300*	Smoking (pack/year) FEF25–75 (%)	0.101	–0.315
Diving year PEF (%)	0.364	–0.138	Smoking (pack/year) PEF (%)	0.336	0.210

FVC — functional vital capacity; FEV1 — forced expired volume in 1 second; FEF25–75 — forced expiratory flow between 25% and 75% of FVC; PEF — peak expiratory flow the deck personnel with similar physiological characteristics. Divers had a mean of 10.2 ± 2.5 years of diving experience. The smoking ratio was 25% in divers and 22.9% in the control group. Authors showed a statistically significant increase in FVC (both in percentage and litres), a decrease in FEF25–75 (both in percentage and litres), and FEV1/FVC. On the other hand, FEV1 and PEF showed no significant change. Recent studies suggest FEF25–75 or FEF25–50 might be more sensitive to change than FEV1. The authors concluded that diving might lead to PFT changes consistent with small airway obstruction [9]. In the study of Pougnet et al. [10], the FEV1/FVC ratio and FEF25(%) significantly decreased in 15 years period ($p = 0.02$). Our study is one of the rare studies comparing the PFT changes of ≥ 20 years of diving experience in a healthy, active occupational diver population [1, 10, 12, 18]. In our research, we found that the FEV1/FVC ratio and FEF25–75(%) values of divers with 20 years or more diving experience were statistically significantly lower ($p < 0.001$, $p < 0.05$, respectively). Small airway diseases can be assessed with obstructive parameters (FEF25–75, FEV3/FVC, 1-FEV3/FVC, FEV3/FEV6), flow-volume curve indices, and lung volumes (FVC, RV, FRC, TLC). While the reduction in FEV1/FVC ratio can be used in determining obstructive ventilation disorder, FEF25–75(%) is the simplest test for small airway assessment [24]. Our findings are consistent with persistent PFT changes, possibly reflecting small airway disease in highly experienced diver populations, similar to previous studies.

During diving, chronic inflammation may occur along with the thickening of the bronchioles or impaired lung elasticity, leading to dynamic compression of the airways during forced expiration [11]. Several factors may influence the airflow limitation in divers. A diver breathes cold and dry gas with a higher density during diving with breathing support [22]. The work of breathing increases due to increased resistance of breathing mainly caused by the regulator and the effects of immersion, including increased gas density [1, 4]. The partial pressures of breathed gases increase during diving [22]. Hyperoxia leads to inflammation and oxidative stress. Similarly, the increase in the partial pressure of nitrogen leads to microbubbles during decompression [1]. These bubbles are filtered through the lungs. However, this process may cause inflammation in the lung's vascular structures and may influence pulmonary function. On the other hand, carbon monoxide and other aromatic gases, water vapour and oil can be involved in the breathing gas mixture due to insufficient cleaning and care of the compressors. These factors may also harm lung tissue [4]. The consensus of an international conference was that deep-diving has weak but definite long term effects on the human pulmonary system and may lead to an increase in total lung capacity and a decrease in small airways conductance and gas transfer capacity [11]. Unfortunately, causes, mechanisms, and the clinical impact of PFT changes still have not been clarified in this relatively healthy group [9]. There should be more prospective studies about the long term effects of diving on pulmonary functions to reveal the clinical impact of these changes.

Occupational diver groups (commercial divers, military divers, firemen divers, saturation divers, scientific divers, SCUBA instructors, ...) are a wide range. Their physical capabilities, diving exposures may differ from each other, even in the same group. The studies were occasionally conducted on specific groups such as military divers or overall occupational diver groups [1, 13, 15, 16, 18]. Nevertheless, commercial divers work in higher-risk environments with physically exhausting tasks and different working conditions, long exposures with various types of equipment, and even different dive profiles than SCUBA instructors. In our study, we also aimed to determine the difference between SCUBA instructors and commercial divers. We did not found any significant difference for PFT parameters between these two different occupational groups. According to our study, tougher diving conditions do not seem to create any difference in pulmonary function changes. Diving experience (year) appears to be the shared main parameter affecting respiratory functions without revealing any related clinical symptom in both occupational groups. However, we cannot reach a definitive conclusion due to the limitations of our study. The number of total dives, diving depth, diving environment, water temperature, diving suit, breathing gases, types of equipment, diving profile, time spent in diving might also influence these PFT changes. It should be known that decompression profiles can be different even between diving companies.

Unfortunately, the previous PFT records of these divers could not be obtained for statistical analyses. Sports activities other than diving were not found in medical records of divers, which might influence pulmonary functions. A combination of sports activities may increase the strength and endurance of the inspiratory muscles [15, 25]. The military divers who are more physically trained than all occupational diving groups were excluded from our study. However, the diving effect on respiratory functions should be analysed solely. Besides, diving exposure should be defined with diving years, diving depths, and mixed gas experience. Unfortunately, we only had the data on the diving years. Also, the small sample size is another limitation. Lastly, further functional examinations such as the carbon monoxide diffusion test and functional residual capacity tests might reveal useful data. These were the main limitations of our study due to the retrospective nature of data collection.

CONCLUSIONS

In conclusion, occupational diving seems to lead PFT changes related to small airway disease after long years of exposure without any clinically relevant symptoms such as dyspnoea. There is no consensus about these changes, whether they are a pathological or physiological consequence of diving. Other environmental factors, such as high air pollution, may be confounding factors that might be studied in further studies. After determining the leading cause of these PFT changes, which is shown repeatedly in many studies, it will help to work on measures to be taken in terms of long-term respiratory health in occupational divers.

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CONFLICTS OF INTEREST

The authors report no conflict of interest.

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