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Comparison of lung function values of trained divers in 1.5 ATA hyperbaric chamber after inhaling 100% oxygen and regular air: a crossover study

The authors declare no financial disclosure

Abstract

Introduction: Diving is an activity performed in more than 1 atmosphere absolute pressure (ATA) either underwater or in a hyperbaric chamber. We aimed to compare lung function values of trained divers in 1.5 ATA hyperbaric chambers after inhaling 100% oxygen and regular air.

Methods: This experimental study with crossover design involved 18 trained divers in 1.5 ATA hyperbaric room, which is equivalent to a 5-meter depth. The eighteen subjects as the supplementation group, using oro-nasal mask, inhaled 100% oxygen for 30 minutes followed by a one-day washout period. The subjects were then crossed-over into control group inhaling only regular air for 30 minutes. Lung function test was performed before and after supplementation.

Results: In eighteen subjects inhaling regular air, there was a significant difference ($p < 0.05$) in FEV_1/FVC, PEF, FEF25, FEF50, and FEF75. Whereas in eighteen subjects inhaling 100% oxygen, significant difference ($p < 0.05$) was observed not only in FEV_1/FVC, PEF, FEF25, FEF50 and FEF75, but also in FEV_1.

Conclusions: There were significant differences in lung function, especially in dynamic volume of trained divers in 1.5 ATA hyperbaric chamber after inhaling 100% oxygen and regular air for 30 minutes; while there were no significant differences in lung capacity (VC and FVC) in the both groups. Lung function returned to normal following supplementation with a 1-day washout period.

Key words: spirometry, ventilation, hyperbaric oxygenation, diving

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Introduction

Diving has been performed since ancient times for underwater works, but recently, people dive for recreation and sports, taking the advantage of the development of diving technology that has allowed divers to get to places previously impossible to reach [1–4]. Diving is an activity performed in more than 1 atmosphere absolute pressure either underwater or in a hyperbaric chamber, which affects body structure and function [5, 6]. Increase in underwater environmental pressure is significant. Underwater pressure will increase by 100 kPa, which is equivalent to 1 atmosphere when divers descend as deep as 10 meters [1, 5]. The increase in pressure is followed by the increase in density of inhaled gas, which increases respi-

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ratory work [7]. The use of diving tools, such as self-contained underwater breathing apparatus (scuba), may increase dead space and airway resistance [5]. Clark *et al.* [8] studied 12 men who went through pulmonary function test after using oxygen at a depth of 3 ATA for 3.5 hours and found a 2% decrease in vital capacity (VC), 2.9% decrease in forced vital capacity (FVC), 5.9% decrease in forced expiratory volume in 1 second (FEV_1), and 11.8% decrease in forced expiratory flow $(FEF)_{25-75\%}$.

This study aimed to compare lung function values of trained divers in 1.5 ATA hyperbaric chambers after inhaling 100% oxygen and regular air, as well as the contributing factors.

Material and methods

This study is an experimental study with crossover design conducted among 18 trained divers to compare lung function values of the divers using closed circuit scuba inhaling 100% oxygen for 30 minutes and open circuit scuba inhaling regular air for 30 minutes after a washout period in between in 1.5 ATA hyperbaric chamber equivalent to diving at a 5-meters depth. The study had been granted permission and fulfilled all research requirements as well as the code of ethics of the Faculty of Medicine Universitas Indonesia (Approval Number: 303/UN2.F1/ETIK/2015). All subjects signed the written informed consent to participate in the study.

Lung function test was performed using a SPIROBANK II that had been calibrated outside the 1.5 ATA hyperbaric chambers as the baseline, as well as inside the chamber. The study used the American Thoracic Society (ATS) criteria test. Spirometry results were compared with the Indonesian Pneumobile Project data as a reference. The study was performed between April–May 2015 in the Indonesian Navy Health Institute (Lakesla) at Surabaya, Indonesia.

The subjects were 18 trained divers in Surabaya who met the inclusion and exclusion criteria. The inclusion criteria in the study were as follows: trained diver; man; aged 20–40, and willing to follow all procedures and time frame of the study. We excluded subjects with abnormality in physical and radiological examination. Patients with asthma, chronic obstructive pulmonary disease and history of tuberculosis were also excluded. The drop out criteria in the study was the inability to perform Valsalva maneuver and to continue the study. We also evaluated the subjective symptoms, such as coughing, dyspnea, breathlessness, and chest discomfort — after the intervention.

Table 1. Subjects characteristics

Variable	Subject	
	n	%
Age (years)		
20–29	13	72.2
30–35	3	16.7
36–40	2	11.1
BMI		
Normal	7	38.9
Risk	8	44.4
Obesity I	3	16.7
Diving experience (years)		
1–9	16	88.9
10–19	2	11.1
20–29	0	0.0
Smoking habit		
Non-smokers	5	27.8
Former	3	16.7
Active smokers	10	55.6

Most of the subjects were 20–29 years old (72.2%) with the youngest being 24 years old and the oldest — 40 years old. Most participants had a body mass index in "at risk" group (44.4%). The subjects' years of diving experience were mostly 1–9 years (88.9%), while the fewest group were people with 10–19 years of practice (11.1%). Most subjects were active smokers (55.6%) with 9 subjects in the mild category based on Brinkman index (Table 1).

Statistical method

Data distribution normality test was performed using the Shapiro-Wilk test. Normal distribution data was presented as mean ± standard deviation (SD) and abnormal distribution data was presented as median (minimal-maximal). We used the T-test to compare mean value in normal distribution data and non-parametric test, such as the Mann-Whitney test and Wilcoxon signed rank test if data distribution was abnormal. All p-values < 0.05 were considered statistically significant. All statistical analyses were performed using Statistical Package for the Social Science (SPSS) software version 15.0 for Windows (Chicago, IL, USA).

Table 2. Comparison of lung function values before and after inhaling 100% oxygen and inhaling regular air

Parameters	Regular air			100% Oxygen		
	Before	After	p	Before	After	p
VC (ml)	3,695 (3,300 to 5,030)	3,675 (3,390 to 4,540)	0.454*	3,780 (2,880 to 4,620)	3,790 (3,370 to 4,730)	0.330*
FVC (ml)	3,755 (3,400 to 4,780)	3,790 (3,240 to 4,720)	1.000*	3,670 (3,410 to 5,080)	3,695 (3,320 to 4,930)	0.960*
FEV_1 (ml)	3,235 (2,920 to 4,270)	3,325 (2,840 to 4,220)	1.430*	3,377 ± 399	3,311 ± 388	0.00**
FEV_1/FVC (%)	88.2 ± 4.1	84.5 ± 3.7	0.00**	87.3 ± 3.5	85.8 ± 3.6	0.00**
PEF (l/sec.)	9.45 ± 1.14	7.81 ± 0.86	0.00**	9.15 ± 1.04	7.87 ± 0.86	0.00**
$FEF_{25\%}$ (l/sec.)	7.75 ± 1.19	6.02 ± 0.92	0.00**	7.36 ± 1.21	6.22 ± 0.92	0.00**
$FEF_{50\%}$ (l/sec.)	4.57 ± 0.88	3.92 ± 0.64	0.00**	4.48 ± 0.88	3.98 ± 0.72	0.00**
$FEF_{75\%}$ (l/sec.)	2.00 ± 0.59	1.70 ± 0.49	0.00**	1.92 ± 0.57	1.77 ± 0.40	0.00**

*sign test;**paired T-test; Shapiro-Wilk test was employed to determine the normal distribution of data. Normal distribution data were presented as mean ± SD, and abnormal distribution data were presented as median (min–max). Lung functions of the both groups were compared before and after inhalation. $P < 0.05$ indicates a significant difference between 2 groups

Table 3. Comparison of difference in lung function values between group inhaling 100% oxygen and regular air

Parameter	Δ 100% Oxygen before and after	Δ Regular air before and after	p
VC (ml)	0.0 (–200 to 680)	50 (–490 to 210)	0.975*
FVC (ml)	–3.33 ± 13.48	–8.33 ± 14.94	0.917**
FEV_1 (ml)	–125 (–610 to 20)	–60 (–400 to 180)	0.019*
FEV_1/FVC (%)	–3.5 (–12.2 to –0.6)	–1.75 (–6.2 to 6.4)	0.034*

*Mann-Whitney test; **independent t-test; differences of lung function before and after inhalation (Δ value) were measured in the both groups. Data distribution was determined by Shapiro-Wilk test. Normal distribution data was analyzed by independent t-test and abnormal distribution data was analyzed by Mann-Whitney test. There were significant reductions in FEV_1 and FEV_1/KVP ratio in the both groups with the 100% oxygen group showing greater reduction. $P < 0.05$ indicates a significant difference

RESULTS

First, we analyzed the changes of lung function values before and after inhalation interventions of the both groups. We found a significant reduction in FEV_1, FEV_1/FVC, PEF, $FEF_{25\%}$, $FEF_{50\%}$, and $FEF_{75\%}$ ($p < 0.05$) in the group inhaling 100% oxygen (Table 2). However, there were no significant changes in terms of VC and FVC in this group. In the group inhaling regular air, there was a significant reduction in FEV_1/FVC, PEF, $FEF_{25\%}$, $FEF_{50\%}$, and $FEF_{75\%}$ ($p < 0.05$) accompanied by changes in FEV_1, VC, and FVC but it was not statistically significant ($p > 0.05$).

Next, we compared the changes of lung function values between the group inhaling 100% oxygen and the group inhaling regular air. Basing on the analysis of Table 3, the group of 100% oxygen inhalation had lesser increment in terms of VC and FVC compared to group of regular air but this was not significant ($p > 0.05$). However, the 100% oxygen inhalation group had significantly more remarkable reduction in terms of FEV_1 and FEV_1/FVC compared to the group of regular air ($p < 0.05$).

We then contrasted the lung function values of the both groups before and after washout period (Table 2). Compared to the previous washout period, we observed an increased VC and a reduction in FVC, FEV_1, and FEV_1/FVC after washout period in the group of 100% oxygen inhalation, however, it was not statistically significant ($p > 0.05$).

In the group inhaling 100% oxygen, the after -supplementation VC, FVC, FEV_1 and FEV_1/FVC were compared with the after-washout period. We found a decreased VC, FVC and increased FEV_1 as well as increased FEV_1/FVC but they were not statistically significant ($p > 0.05$).

Table 4. Correlation of age, BMI, diving experience, and smoking habit with lung function values in the both groups

Lung function	Variable	Age		BMI		Diving experience		Smoking habit	
		R	p	R	p	R	p	R	p
VC	100% O_2	–.665	0.003	–.37	0.131	–.46	0.054	–.256	0.305
	Regular	–.437	0.072	–.27	0.279	–.409	0.092	–.343	0.164
FVC	100% O_2	–.615	0.007	–.38	0.120	–.358	0.144	–.374	0.126
	Regular	–.603	0.008	–.402	0.098	–.358	0.144	–.188	0.454
FEV_1	100% O_2	–.672	0.002	–.498	0.035	–.512	0.03	–.326	0.186
	Regular	–.683	0.002	–.518	0.028	–.477	0.045	–.238	0.341
FEV_1/FVC	100% O_2	–.370	0.131	–.236	0.347	–.477	0.045	–.014	0.957
	Regular	–.302	0.223	–.359	0.144	–.375	0.125	–.254	0.309

Correlation analysis was performed using Spearman-rho test because data distribution was abnormal after cross tabulation. $P < 0.05$ indicates a significant correlation. BMI was correlated with FEV_1, diving experiences was correlated with FEV_1. Generally, age was correlated with the lung function, except FEV_1/FVC

Finally, we analyzed the correlation of age, BMI, diving experience, and smoking habit with lung function values in the both groups. In the Table 4, a statistically significant difference was observed in the median of test parameters in 100% oxygen group, especially regarding the effect of age on VC ($p < 0.05$). In the regular air group, a correlation between age with FEV_1 ($p < 0.05$) and diving experience with FEV_1 ($p < 0.05$) were observed. BMI was only correlated with the FEV_1 in the both groups; meanwhile smoking habit was not correlated with all lung function values.

Discussion

According to Clark *et al*. [8], the use of prolonged oxygen therapy might cause oxygen poisoning to the lung if exposed for 16–19 hours in 1.5 ATA depths with the symptoms of shortness of breath during exercise or rest; however, improvement of symptoms could occur in 8–14 hours. This study used a one-day washout period to prevent oxygen poisoning. Compression was performed in 2 minutes to achieve 1.5 ATA depths, with gradual resurfacing for 5 minutes in order to prevent barotrauma.

The study was performed at a 5-meter depth or 1.5 ATA, which was the minimum limit of pure oxygen usage. According to Egstrom *et al.* [9], pure oxygen limit for the use of closed circuit is up to the depth of 1.6 ATA. Open circuit scuba diving was performed at a 18–39-meter depth with a maximum ocean current velocity of 0.5 meter/ /second. Trained diving using closed circuit scuba is performed at a less than 10-meter depth with a maximum of 14 meters. Closed circuit scuba is used for training purposes, which requires special skill and confidentiality [6, 10, 11].

The study comprised predominantly young (20–29 years old) divers, most subjects had a BMI categorized as "at risk" group and diving experience were mostly 1–9 years. The study obtained the same result as that of Tetzlaff *et al.* [12] which involved military divers with a mean age amounting to 28 years.

We found an increase in VC value and decrease of FVC, FEV_1, as well as FEV_1/FVC. Brian *et al*. [3] stated that when breathing with 100% oxygen, respiration drive was zero due to an extremely high concentration of oxygen that reduced carbon dioxide exchange and subsequently caused CO_2 retention and collapse of the alveoli. During diving, diving stressors by an increase in hydrostatic pressure, gas density, gas partial pressure, and gas solubility might inhibit the raise of lung function values and thereafter decrease lung function.

The study showed an asymptomatic decrease of lung function that might occur due to the fact that the subjects were trained divers with respiratory muscles that are able to compensate the decrease of lung function. The result of the study differs from that of Clark *et al.* [8] which was performed among 12 patients using 100% oxygen in 3 ATA depths for 3.5 hours. The study found a 2% decrease in VC and a 2.9% decrease in FVC, but obtained the same result in terms of FEV_1 value, with a decrease of 5.9%. The outcome of the study mirrors that of Shykoff *et al*. [13] who conducted study with 100% oxygen in 1.35 ATA for 8 hours and found a decrease in FVC and FEV_1 value of 10.7% and 11.0%, respectively. The same result was found in the study by Tetzlaff *et* *al.* [12] carried out among 37 divers using closed circuit scuba, which showed a decrease in FVC value ranging from 5.89 ± 0.67 l to 4.83 ± 0.64 l, and a decrease in FEV_1 value ranging from 4.86 ± 0.62 l to 4.83 ± 0.64 l.

There were changes in the lung function values of eighteen subjects in the regular air group before and after inhaling regular air for 30 minutes in 1.5 ATA hyperbaric chambers. We observed an increased VC and a decrease in FVC, FEV_1 and FEV_1/FVC. Reduced lung function values after inhaling regular air in 1.5 ATA hyperbaric chamber for 30 minutes might occur due to diving stressors in diving environment, such as increased hydrostatic pressure, gas density, and oxygen partial pressure, which will inhibit certain stimuli, preventing the increase of lung function [3].

The gas density in 100% oxygen is greater than that of regular air, and inhaling 100% oxygen in a hyperbaric chamber can cause edema and inflammation. The decrease of lung function in 100% oxygen is therefore greater than that of regular air. Inhaling 100% oxygen can also cause the alveoli to collapse; however, the respiratory muscles were able to compensate these changes therefore the subjects did not exhibit any symptoms. This study obtained the same result as that by Clark *et al.* [8], who used air in the pressure of 1.5 ATA after 3.5 hours and showed a 1.6% decrease in FEV_1. The study also achieved the outcome mirroring that of Shykoff *et al.* [13] who used air mixture. The study found similar FVC and FEV_1 values but with reduction rates of 9.5% and 10.2%, respectively [5].

We revealed that lung function values before pressurization to 1.5 ATA in a hyperbaric chamber and after a one-day washout period was similar. In other words, lung function values after a one-day washout period was almost near the baseline value, hence it could be said that lung function was reversible in physiological condition consistent to the adaptive theory [14].

There were several factors affecting lung function values in the both groups, for example the effect of age on VC. In the regular air group, there was a correlation between age and diving experience with FEV_1. Most of the study subjects were active smokers but the FEV_1/FVC value was more than 80% of the predticted value. Consistently with the study by Tezlaff *et al.* [12], neither smoking nor non-smoking military divers had affected lung function. However, in a 5-year longitudinal study with military divers using closed circuit scuba, Tezlaff *et al.* [2] also found that FEV_1 in smokers declined faster than in non-smokers, although the difference was not significant. Lung function values will physiologically reach the highest level at the age of 19–21 and start declining at the age of 25 for approximately 25–30 ml with increasing age [15].

Study limitation

This was a study with cross-sectional design; therefore it only obtained the result at a specific point in time. The study period depends mostly on the unit and could only be performed after finishing patient hour or outside office hours. Another study limitation was a relatively small sample.

Conclusion

There were significant differences of lung function especially in dynamic volume and expiratory flow while there were no significant differences in lung capacity (VC and FVC) of trained divers in 1.5 ATA hyperbaric chambers after inhaling 100% oxygen and regular air for 30 minutes. Age is the main factor that correlated with lung function in the both groups. Lung function returned to normal following supplementation with a 1-day washout period.

Conflict of interest

The authors declare no conflict of interest.

References:

1. Lee YIl, Ye BJ. Underwater and hyperbaric medicine as a branch of occupational and environmental medicine. Ann Occup Environ Med. 2013; 25(1): 39, doi: 10.1186/2052-4374-25-39, indexed in Pubmed: 24472678.
2. Tetzlaff K, Theysohn J, Stahl C, et al. Decline of FEV1 in scuba divers. Chest. 2006; 130(1): 238–243, doi: 10.1378/chest.130.1.238, indexed in Pubmed: 16840408.
3. Brian JE. Gas exchange, partial pressure gradients and the oxygen window. Department of Anesthesia University of Iowa College of Medicine. 2015: 1–14.
4. Welslau W. Physics of Hyperbaric Pressure. Handbook on Hyperbaric Medicine. 2006: 15–23, doi: 10.1007/1-4020-4448-8_2.
5. British Thoracic Society Fitness to Dive Group, Subgroup of the British Thoracic Society Standards of Care Committee. British Thoracic Society guidelines on respiratory aspects of fitness for diving. Thorax. 2003; 58(1): 3–13, indexed in Pubmed: 12511710.
6. Mahdi H. Pengenalan penyelaman. In: Suryokusumo MG, Avongsa M, Widodo D, Harnanik T. ed. Buku ajar ilmu kesehatan penyelaman dan hiperbarik. Surabaya, Lakesla 2013: 33–54.
7. Bove AA, Lynch JH, Bove AA, et al. Diving medicine: a review of current evidence. J Am Board Fam Med. 2009; 22(4): 399–407, doi: 10.3122/jabfm.2009.04.080099, indexed in Pubmed: 19587254.
8. Clark JM, Jackson RM, Lambertsen CJ, et al. Pulmonary function in men after oxygen breathing at 3.0 ATA for 3.5 h.

J Appl Physiol (1985). 1991; 71(3): 878–885, indexed in Pubmed: 1757324.
9. Egstrom G. Diving Equipment. Bove and Davis' Diving Medicine. 2004: 37–51, doi: 10.1016/b978-0-7216-9424-5.50009-5.
10. Butler FK, Smith DJ. United State navy diving equipment and techniques. In: Bove AA, Smith DJ. ed. Diving medicine 4th edition. WB Saunders, Philadelphia 2004: 547–571.
11. Supervisor of diving U.S. Navy. Closed-circuit and semiclosed circuit diving operations. In: Navy Do. ed. US Navy Diving Manual. Washington: Direction of Commander. Naval Sea System Commando, Washington 2008: 17–19.
12. Tetzlaff K, Friege L, Theysohn J, et al. Lung function in military oxygen divers: a longitudinal study. Aviat Space Environ Med. 2005; 76(10): 974–977, indexed in Pubmed: 16235882.
13. Shykoff B. Pulmonary Effects of Eight Hours Underwater Breathing 1.35 ATM Oxygen: 100% Oxygen or 16% Nitrogen, 84% Oxygen. 2005, doi: 10.21236/ada442924.
14. Suryokusumo MG. Underwateractivity. In: Suryokusumo MG, ed. Minatan kedokteran hiperbarik pasca sarjana. Jakarta: IKK FKUI. ; 2003.
15. Standardization of Spirometry, 1994 Update. American Thoracic Society. American Journal of Respiratory and Critical Care Medicine. 1995; 152(3): 1107–1136, doi: 10.1164/ajrccm.152.3.7663792.