Changes in pulmonary function in hyperbaric chamber inside attendants: a case-control study

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ABSTRACT

Background: Inside attendants (IAs) exposed to high pressure during hyperbaric oxygen (HBO_2) therapy. The aim of this study was to evaluate the alterations of pulmonary functions in IAs over time.

Methods: IAs in our hyperbaric center constituted the IA group (n=11). A sex- and age-matched control group (n=15) was constituted from hospital staff who had not dived or been exposed to hyperbaric environments before. We measured the respiratory function of all subjects at two time points:
1) at the start of the study; and
2) 12 months after the first measurement.
The following parameters were recorded: forced vital capacity (FVC), forced expiratory volume in one second (FEV1), rate of FEV1 to FVC (FEV1/FVC%), forced expiratory flow at 25% to 75% vital capacity (FEF25-75%), forced expiratory flow at 50% vital capacity (FEF50%), forced expiratory flow at 25% vital capacity (FEF25%).

Results: Both groups were similar in terms of age, sex, smoking and body mass index. We found that FEV1, FEV1/FVC%, FEF25-75% and FEF50% significantly reduced in both groups after 12 months ($p<0.05$). However, the rate of change in all parameters was similar in both groups ($p>0.05$). In the IA group, the total number of exposures within the 12 months was positively correlated with the rate of reduction in FEF25% (r=0.788, p=0.004).

Conclusion: Working as an IA does not deteriorate pulmonary function in the short term. However, there is a need for long-term follow-up studies.

INTRODUCTION

Hyperbaric oxygen (HBO_2) therapy involves intermittent inhalation of 100% oxygen in monoplace or multiplace hyperbaric chambers. Multiplace hyperbaric chambers treat more than one patient at a time, and an inside attendant (IA) accompanies patients inside the chamber. The duties of a hyperbaric chamber inside attendant are to ensure that the patients adapt to the hyperbaric chamber, notify the responsible doctor in case of any emergencies during treatment, and subsequently carry out the doctor's instructions and apply any necessary safety measures during possible emergency situations.

Multiplace hyperbaric chambers are pressurized with air, and while the patients inhale 100% oxygen via a mask or hood the IA breathes pressurized ambient air. The inside attendant generally enters the chamber no more than once a day if possible, to ideally minimize decompression obligations and residual nitrogen. A routine HBO_2 therapy session lasts 90-120 minutes at 2 to 2.5 atmospheres absolute (ATA). This means that inside attendants spend 90-100 minutes at a depth of approximately 14 meters. For this reason, hyperbaric exposure-related acute conditions such as decompression sickness [1] and middle ear barotraumas [2] have been reported in inside attendants. The chronic effects of repetitive exposure to high pressure on IAs are a concern and their effects on the skeletal and central nervous system of inside attendants has been studied previously [3,4].

KEYWORDS: hyperbaric chamber attendant; pulmonary function

There are primary and secondary factors that may lead to pulmonary function change during hyperbaric exposure. Pressure may be expressed as diving depth, diving time and the inhaled gas mixture, primary factors that may affect pulmonary function [5]. It has been reported that venous gas microemboli, which are filtered by pulmonary circulation, and secondary hyperoxia may cause inflammatory reactions in the lungs [6,7]. The respiratory resistance and respiratory workload increases by increased density of inhaled gases in divers as well as the limitation of the thorax restriction due to immersion and the resulting compression on the wetsuit. As a result, vital capacity increase has been reported in divers [8]. In addition to increase in respiratory resistance, increase in pulmonary capillary pressure due to immersion has caused pulmonary edema in some divers [9].

To our best knowledge, no study has been carried out before to evaluate the effect of working as an inside attendant on pulmonary functions. The objective of our study was to measure the alterations of pulmonary functions after 12 months in hyperbaric chamber IAs and compare these alterations with a non-pressure-exposed control group.

MATERIALS AND METHODS

This study was carried out between 01 February 2014 and 20 March 2015 at the Department of Underwater and Hyperbaric Medicine, Gulhane Military Medical Academy. The ethics board of our hospital approved the study protocol. Hyperbaric chamber inside attendants working in our department formed the IA group. A sex- and age-matched control group was established from hospital staff who had not been exposed to the hyperbaric chamber or who had dived before. All subjects gave informed consent to participate in the study. Those who had any form of lung disease before the study were excluded.

The IA group included 11 individuals working in the hyperbaric chamber, and 16 individuals who were not exposed to pressure comprised the control group. The IAs in our department attended both routine and emergency HBO_2 therapy sessions, which were performed in a multiplace hyperbaric chamber. A routine HBO_2 therapy session constitutes three 30-minute oxygen periods interspersed with two five-minute air breaks at 2.4 ATA. Emergency HBO_2 therapy session protocol was the same as routine HBO_2 therapy protocol. Inside attendants were advised to breathe oxygen during the last 15 minutes of the treatment.

Measurement of respiratory function

We measured respiratory function of all subjects at two time points:
1) at the start of the study; and
2) 12 months after the first measurement.

A Quark PFT1/Spirometry Module (Rome, Italy) device was used. Flow rates were measured at a fraction of vital capacity expired. All measurements were made without subjects exercising and after five minutes of rest. The subjects were reminded that they should refrain from smoking for at least four hours before the test and refrain from eating at least two hours before the test. The tests on IAs were carried out at least 24 hours after the last hyperbaric exposure.

The tests were conducted in the same ambient laboratory temperature and at the same times (between 14.00-16.00 hours). The same technician, who was blinded to the subjects' groups, carried out all measurements with the same device after daily calibration. The test results were compared with expected values (predicted values) for individuals of the same age, height and sex; these values were expressed as percentages. An expected value of ≥80% was deemed normal. Each measured value was expressed as a percentage of the expected value according to the laboratory values of the European Respiratory Association [10].

The following parameters were recorded at the beginning of the study and after 12 months:

1. forced vital capacity (FVC)
2. forced expiratory volume in one second (FEV1)
3. ratio of forced expiratory volume in one second to forced vital capacity (FEV1/FVC %)
4. peak expiratory flow rate (PEF)
5. mean forced expiratory flow rate between 25% to 75% of vital capacity expired (FEF 25-75%),
6. forced expiratory flow rate at 25% of vital capacity expired (FEF25%),
7. forced expiratory flow rate at 50% of vital capacity expired (FEF50%).

Table 1. Characteristics of inside attendants and controls

	inside attendants n = 11	control subjects n = 15	p*
age (years)	33.7 ± 7.6	33.3 ± 6.2	0.714
sex (m/f)	3/8	4/11	1.0**
body mass index (kg/m2)	24.0 ± 54	22.9 ± 3.4	0.856
smoking (n)	3	3	1.0**

*Mann-Whitney U test **Fisher's exact test

Statistical analysis

The statistical analysis was carried out with SPSS 15.0 (SPSS Inc., Chicago, Illinois) software package. The variables that have normal distribution were presented as mean ± standard deviation (SD) and those that do not have normal distribution were presented as median (minimum-maximum). The Mann-Whitney U test was used for continuous variables to compare inside attendants and control groups, while Fisher's exact test was used for discrete variables. The Spearman correlation test [the same as 'Spearman's rank correlation coefficient'] was used to evaluate the linear correlation between the variables. A p-value of less than 0.05 was accepted as statistically significant.

RESULTS

One subject in the control group was excluded from the study because she did not attend the second test. The study was carried out with 11 subjects in the inside attendant group and 15 subjects in the control group. The groups were similar in terms of age, sex, body mass index and smoking (Table 1).

The average number of sessions attended by the IAs during the 12-month study period was 71.5 ± 45.2 (25-125); with the addition of the dives before the study the total number of session was 311.2 ± 328.0 (54-856). The average of the time worked as an inside attendant was 38.7 ± 25.5 (18-84) months.

Pulmonary function test (PFT) results of IAs and controls were presented in Tables 2 and 3, respectively. Pulmonary function of inside attendants and control subjects measured at first examination were similar (p>0.05). We found that FEV1, FEV1/FVC%, FEF25-75% and FEF50% significantly decreased after 12 months both in IAs and control subjects. However, the comparison of pulmonary function alterations in both groups revealed that these parameters changed in a similar amount in both groups (Table 4).

Table 2: Pulmonary function test results measured before the study and at 12 months in inside attendants*

	inside attendants (n= 11)			
	before	after	difference	p**
FVC	104.6 ± 12.3	103.7 ± 13.0	0.9 ± 5.8	0.754
FEV1	103.2 ± 12.7	99.5 ± 13.3	3.7 ± 5.7	0.048
FEV1/FVC%	84.4 ± 4.3	82.1 ± 4.7	2.2 ± 2.2	0.012
FEF25-75%	88.8 ± 15.5	82.0 ± 16.3	6.9 ± 8.2	0.029
PEF	103.5 ± 10.3	101.9 ± 9.7	1.6 ± 10.3	0.789
FEF25%	115.6 ± 11.1	110.4 ± 10.2	5.3 ± 10.7	0.241
FEF50%	99.3 ± 18.3	92.2 ± 18.7	7.1± 10.6	0.041

Table 3: Pulmonary function test results measured before the study and at 12 months in control group*

	control subjects (n=15)			
	before	after	difference	p**
FVC	100.6 ± 12.2	100.5 ± 12.4	0.1 ± 4.6	0.932
FEV1	99.9 ± 10.4	97.2 ± 11.0	2.7 ± 4.1	0.024
FEV1/FVC%	85.2 ± 5.5	83.0 ± 5.2	2.3 ± 2.3	0.003
FEF25-75%	93.2 ± 22.5	85.6 ± 23.8	7.6 ± 7.3	0.005
PEF	103.4 ± 14.0	101.7 ± 18.6	1.7 ± 10.0	0.271
FEF25%	113.4 ± 17.5	111.7 ± 20.5	1.7 ± 10.8	0.531
FEF50%	107.5 ± 25.7	99.7 ± 26.5	7.7 ± 12.6	0.021

*Mean ± SD **Mann-Whitney U test

FVC: forced vital capacity

FEV1: forced expiratory volume in one second

FEV1/FVC%: ratio of forced expiratory volume in one second to forced vital capacity

FEF25-75%: forced expiratory flow at 25% to 75% of vital capacity

FEF50%: forced expiratory flow at 50% of vital capacity

FEF25%: forced expiratory flow at 25% of vital capacity

We analyzed the correlation between the number of sessions attended during the 12-month study period and the amount of alterations in PFT parameters (Table 5). A positive correlation was determined between the total number of exposure within the 12 months and the reduction in FEF25% in inside attendants. (r=0.788, p=0.004). However, we did not find any correlation between the total number of exposures within the 12 months and other PFT parameters (Table 5).

Table 4. Comparison of changes in pulmonary function test parameters in inside attendant and control groups*

	inside attendants n= 11	control subjects n= 15	p **
FVC	-1 (-8:13)	1 (-7:8)	0.815
FEV1	3 (-3:15)	3 (-4:11)	0.917
FEV1/FVC %	2 (-2:7)	2 (-1:7)	0.654
FEF25-75%	7 (-8:23)	10 (-4:22)	0.755
PEF	-2 (-12:26)	3 (-26:17)	0.467
FEF25%	0 (-7:28)	3 (-23(23)	0.603
FEF50%	8 (-5:32)	2 (-7:35)	0.855

*Median (minimum: maximum) **Mann-Whitney U test

Table 5. Correlation between pulmonary function test parameters and the number of sessions within 12 months in inside attendants (n = 11)

	r*	p
FVC	-0.103	0.763
FEV1	-0.007	0.984
FEV1/FVC%	0.172	0.613
FEF25-75%	0.070	0.838
PEF	0.523	0.098
FEF25%	0.788	0.004
FEF50%	0.056	0.870

*Spearman's Correlation Test

FVC: forced vital capacity

FEV1: forced expiratory volume in one second

FEV1/FVC%: ratio of forced expiratory volume in one second to forced vital capacity

FEF25-75%: forced expiratory flow at 25% to 75% of vital capacity

FEF50%: forced expiratory flow at 50% of vital capacity

FEF25%: forced expiratory flow at 25% of vital capacity

DISCUSSION

Pulmonary function tests were administered to the health care staff who worked as inside attendants in the hyperbaric chamber and the control group comprising hospital staff who did not enter the hyperbaric chamber. These results were compared at the start of the study and again after 12 months; no differences were observed between the groups. An overall assessment of the results indicates that PFT changed in IAs and control subjects in a similar amount in one year.

We did not find any long-term study that investigated the effect of pulmonary function on inside attendants. Although patients and inside attendant are exposed to the same pressure during treatments, they breathe different gases. While inside attendants breathe air in most of the treatment, patients breathe 100% oxygen. The partial pressure of oxygen (PO_2) at 14 meters is 50 kPa while breathing air; it is 240 kPa while breathing pure oxygen at the same depth. Additionally, attendants breathed pure oxygen during the last 15 minutes of the dives. Therefore, studies looking at the pulmonary functions of patients receiving HBO_2 therapy were not included in the discussion. Instead, we compared our results with divers since they constitute a similar group to inside attendants in terms of hyperbaric exposure and air-breathing during diving.

In a retrospective study, Richard, et al. found that FEF75%, FEF50% and FEV1/FVC% ($p<0.01$) significantly decreased and total lung capacity increased ($p=0.03$) in professional divers during a 10-year period [11]. The change in the FEV1/FVC% rate was found to be proportional to the diving time and the number of dives performed in 10 years ($p<0.01$). There was no control group, and PFT values of the divers taken at the beginning and at the end of 10 years were compared.

Skogstad, et al. monitored the pulmonary functions of 87 professional divers for six years [12]. A total of 64 non-smoking police officers were used as a control group. The annual decreases in FVC and FEV1 in divers were significantly higher compared to the decrease in the control group ($p<0.001$). The median dive depth for six years was 44 (10-100) meters, while the median dive frequency was 196 (37-2,000) dives. Even if the diving depths varied, 40% of dives were deeper than 10 meters, and some went to a depth of 100 meters. In the multiple regression analysis, annual decreases of MEF25% and MEF75% were correlated with the cumulative number of dives ($p<0.05$).

The dive depth of our study was 14 meters and the dive frequency was approximately once every three days. We believe that the reason for no changes in the pulmonary functions of the inside attendants was the shallow diving depth. Such a depth and frequency may not cause a noticeable difference in pulmonary functions of inside attendants compared to non-diving controls.

Davey, et al. analyzed the annual medical records of 858 divers and reported a positive significant correlation between maximum diving depth and FVC [13]. This correlation was not found with FEV1. Yet, a significant negative correlation was found with FEV1/FVC%. This index was associated positively with number of years exposed to diving. In the longitudinal analysis of 255 divers for a minimum of five years, it was determined that annual FVC change was associated with the change in maximal depth. However, the change in maximal depth was not associated with FEV1 and FEV1/FVC%. A significant decrease was reported for FEF75% in comparison with the control group. It was asserted that vital capacity and flow rate of small lung volumes were affected by diving depth. Additionally these measures were affected proportionally by secondary airway-narrowing due to loss of elastic lung tissue associated with diving. It is evident that these effects are related to diving depth and are not observed in shallow depths. In accordance with this data, repeated diving into shallow depths such as 14 meters did not incur significant changes in the lung capacities of the inside attendants.

Watt, et al. analyzed pulmonary function in 224 divers after three or four years and in 123 divers after five or more years [14]. Analysis showed that FVC decreased in both groups, but this decrease was more significant in divers after five or more years. The maximum diving depth of the divers in the first group was 144 meters, while the depth was 166 meters for the second group. It was reported that the decrease in FVC was not associated with age, smoking, maximum diving depth and a career in diving. A decrease was also evident in the FEV1; however, it was less distinct than the decrease in FVC. According to the researchers, the result would be more apparent if a study covering 15-20 years were executed and the decrease in the FVC of the divers amounted to 1.5-2 liters. Factors other than diving career were not associated with the change in pulmonary functions. This study differs from the other studies because it shows the importance of dive depth.

In a study carried out by Thorsen, et al. 24 saturation divers were tested after eight deep dives to depths of 300-450 meters and then again after one year; 22 were retested after four years [15]. A total of 28 different saturation divers were used as reference. The yearly decrease in FEV1 was significantly higher than the expected value. The values for FEF50%, FEF75% and FEF50-75% also differed from expected values. In other words, this study foresees a possible change in PFT values if the dives are deep enough.

A longitudinal study carried out by Bermon, et al. regarding 20 divers during nine years revealed a decrease in FEV1 as well as maximum mid-expiratory flow. They asserted that this was caused by the chronic effect of diving on the small airways [16].

Lucas, et al. measured the pulmonary function of 31 professional divers during the first year and again five years later and found a pronounced decrease in FEF75% ($p<0.006$), which was associated with diving depth [17])]. A pronounced decrease was also observed in the diffusing capacity or transfer factor of the lung for carbon monoxide (DLCO) ($p<0.02$), which was associated with dive frequency.

Chong, et al. reported that FEV1/FVC% significantly reduces with time in navy divers (from 87.0% to 85.0% of predicted in five years) [18]. Although the decrease was significant, its clinical significance was questionable, and Chong, et al. concluded that lung functions of navy divers do not deteriorate in the long term.

In our study, we found that FEV1, FEV1/FVC%, FEF25-75% and FEF50% significantly reduced after 12 months both in inside attendants and control subjects. The observed changes in the pulmonary functions, although statistically significant, are not substantial enough to generate a clinical symptom. The clinical significance of these alterations is not clear.

In a study carried out by Tetzlaff, et al. in 2006 the pulmonary function test results of 468 military divers over five years were compared with the values of a control group composed of 122 submariners. It was reported that the decrease in FEV1 was not significant between two groups [19]. Similarly, we found that the decline of FEV1 after one year was not significantly different in inside attendants and non-diving controls.

An overall assessment of the studies shows that dive frequency and dive depth are important factors. The significance of very deep diving and time spent in the diving profession in terms of lung function tests were reported in the studies. However, these values, which are significant in terms of PFT values, do not always correspond with clinical values. In our study the diving frequency was once every three days at shallow depth of 14 meters. No significant decrease in the PFT values of inside attendant staff was observed after one year.

Inside attendants differ from divers because they work in ambient temperatures and sometimes in hot environments. It was concluded that IAs were not exposed to chronic airway obstruction, which is possible in cold environments [20]. It was concluded as well that inhaling ambient air in the hyperbaric chamber would not generate bronchoconstriction, which may be caused by inhaling dry and cold air [21]. Without the effect of immersion, feet are exposed to the same level of pressure as the chest, which is why pulmonary capillary pressure and respiratory tract resistance will not increase. However, partial hyperoxia, which occurs during diving, and the formation of venous gas microemboli may be observed. These different aspects may be the reasons why lung function changes observed in divers were not detected in hyperbaric chamber inside attendants.

LIMITATIONS

This study has limitations. The small number of inside attendants could be a limitation, but all IAs working in our clinic were included in the study. Secondly, pulmonary function tests were measured after 12 months. A longer follow-up may demonstrate a larger pulmonary function changes in inside attendants compared to controls. Thirdly, due to a technical error our lung function tests did not include FEF75%, which might be important for our study since it is related to the small airways.

CONCLUSION

This study showed that PFT parameters reduced slightly in 12 months both in inside attendant and control groups. Our findings suggest that working as an inside attendant does not deteriorate pulmonary function in the short term. However, the positive correlation between the number of sessions within 12 months and the FEF25% reduction may be an indication of small airway disease. Therefore, there is a need for long-term follow-up studies in larger samples.

Conflict of interest statement

Authors declare no conflicts of interest exist with this submission. ■

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