Longitudinal study of changes in pulmonary function among inside attendants of hyperbaric oxygen therapy

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Abstract
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Introduction: Hyperbaric oxygen therapy (HBOT) administers 100% oxygen in a pressurised chamber at pressures above 1 atmosphere absolute. Inside hyperbaric personnel accompany patients during sessions and breathe compressed air, exposing them to risks like decompression illness and respiratory changes. This study investigated whether hyperbaric exposure affects the long-term lung function of inside hyperbaric personnel.

Methods: An analysis was conducted on spirometry data from 14 personnel working between 2012 and 2023. Lung function tests measured forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), mid breath forced expiratory flow (FEF_{25-75}), and peak expiratory flow (PEF) before and after hyperbaric exposure. Participants were categorised based on age, body mass index, number of HBOT sessions, and duration of employment.

Results: No clinically or statistically significant differences were found in FVC, FEV_1, or PEF measurements before and after hyperbaric exposures ($P > 0.05$). However, FEF_{25-75}, an indicator of small airway function, showed a (mean) 16% reduction in personnel with more than 150 HBOT sessions ($P = 0.038$). A post-hoc analysis confirmed a significant difference in FEF_{25-75} between personnel with fewer than 74 sessions and those with 150 or more sessions ($P = 0.015$). No clinically significant symptoms such as dyspnoea were reported during the study period.

Conclusions: The FEF_{25-75} reduction, without changes in FEV_1, FVC, or PEF, could be due to improper performance of the FVC manoeuvre. Maintaining pulmonary health in inside hyperbaric personnel is essential, emphasising the importance of accurate FVC execution in assessments. Further studies are recommended to explore the long-term implications of these findings and the effects of repeated hyperbaric exposure on respiratory health.

Introduction

Hyperbaric oxygen therapy (HBOT) is the administration of 100% oxygen in a closed chamber at pressures higher than 101.3 kPa (1 atmosphere absolute [atm abs]).[1] There are more than 50 active HBO_2 centres in more than 20 cities in Turkey. Typically, sessions last two hours and operate at a pressure of 243 kPa (2.4 atm abs), although the indication may dictate different pressures and durations.

Inside attendant healthcare personnel (IHP) accompany patients throughout all sessions to assist with pressure equalisation manoeuvres, proper mask-wearing, and prompt action in any potential emergencies that may arise. Inside attendant healthcare personnel only breathe the compressed air in the chamber during sessions; unlike patients, they do not breathe 100% oxygen. Consequently, they are at risk of decompression illness and the adverse effects of pressure changes on various systems and organs of the body. In addition, respiratory function may be affected by exposure to the pressurised environment.[2]

There are many factors that affect respiratory functions. These can be related to genetics, environmental influences, physical conditions, and diseases. The initial circumstances that may impact pulmonary function in IHP are the risk of microbubble formation and the elevated partial pressure of oxygen during sessions. Exposure to high oxygen partial pressure can trigger inflammatory processes in the respiratory system by increasing oxidative stress.[2] Venous gas microbubbles are created during decompression and are expelled from the lungs by exhaling after being transported from nitrogensaturated tissues. Impaired gas exchange, temporary pulmonary hypertension, and pulmonary microvascular inflammation can be triggered by these microbubbles.[3,4]

Furthermore, breathing compressed air in a hyperbaric environment causes an increase in inspiratory effort and airway resistance, as well as a decrease in lung compliance.[5] These could have an impact on respiratory function, particularly airway function.[5,6] However, almost all of what is known about these potentially harmful processes comes from studies of divers rather than hyperbaric chamber exposures.

Airway obstruction is a relative contraindication for working in pressurised environments. Thus, it is crucial for IHP to maintain a healthy respiratory system in order to perform their duties. To make sure they are fit for work, IHP in Turkey have to undergo periodic exams, which include spirometry, to check for any anomalies in lung function.

In our literature review, we found only one study with longitudinal results on changes in lung function in IHP.[7] Nevertheless, there are more studies on changes in pulmonary function in commercial divers due to exposure to a hyperbaric environment.[8–17] The results from these studies have yielded different conclusions regarding pressure-induced changes in lung function in diver and IHP populations.

The objective of this study was to determine whether there has been a change in the lung function (primarily spirometry) of healthcare professionals working at the Akyurt Hyperbaric Oxygen Therapy Center from the time they began working as inside attendants and to examine the potential association between this change and hyperbaric exposure.

Methods

The study was approved by the Gulhane Ethics Board of the University of Health Sciences (02/24: 2024-106), and it was conducted in accordance with the Declaration of Helsinki.

PARTICIPANTS

An audit was conducted on the spirometry tests and postero-anterior chest radiographs of healthcare professionals who worked as IHP at the Akyurt Hyperbaric Oxygen Therapy Center from 2012 to 2023. Personnel who had stopped working prior to the periodic examination and those whose medical records were unavailable or incomplete were excluded from the study.

HYPERBARIC OXYGEN THERAPY PROTOCOL

In the 120-minute treatment protocol that constitutes the vast majority of IHP exposures, the chamber is pressurised with air to 243 kPa (2.4 atm abs) in about 15 minutes. After maintaining this treatment pressure for 90 minutes, decompression is performed over 15 minutes. Patients begin breathing oxygen through a mask or hood at the 10th minute of the treatment. The three 30-minute oxygen periods are separated by two 5-minute air breathing breaks. The accompanying IHP breathe 100% oxygen during the last 10 minutes of the final oxygen period (Figure 1).

DATA

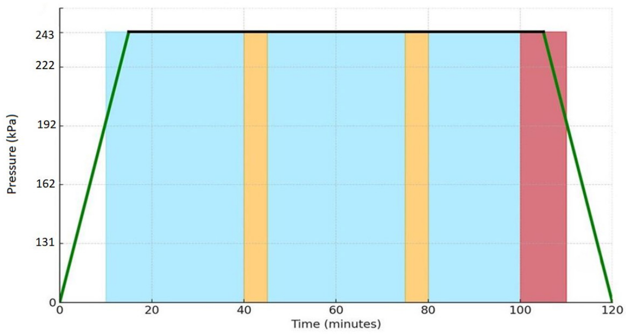
The following information was taken from IHP annual examination records: age, height, weight, medical history, smoking history, history of underwater activities (including recreational and professional diving), sports history, and pulmonary function test (PFT) results (forced vital capacity [FVC], forced expiratory volume at one second [FEV_1], forced expiratory flow at 25%–75% of FVC [$FEF_{25–75}$], peak expiratory flow [PEF], and the FEV_1/FVC ratio). The total number of sessions and the duration of working as an IHP were calculated from the session records.

SPIROMETRY TESTS

In our hospital's spirometry laboratory, spirometry tests were conducted on IHP using the CareFusion Vmax® Encore system (CareFusion, 22745 Savi Ranch Parkway, Yorba Linda, CA 92887). The tests were performed by technicians who had received standardised training in this field. All measurements were performed according to European Respiratory Society/American Thoracic Society task force guidelines. Parameters as above were recorded. The evaluated parameters were compared to the predicted normal values based on the patient's age, gender, height, weight, and ethnicity, expressed as a percentage. The expected values were derived using the Global Lung Initiative (GLI) reference system.[18] Calibration was carried out in accordance with the guidelines provided by the manufacturer.

Figure 1

Hyperbaric oxygen therapy protocol; green lines – compression and decompression phases; black line – constant treatment pressure (243 kPa); blue shading – oxygen breathing periods (mask/hood); orange shading – air breaks (5 minutes); red shading – IHP oxygen breathing during the last 10 minutes of final O_2 period



GROUPS

Age, body mass index (BMI), number of sessions, and the duration of working as an IHP were categorised in the analyses. Age was categorised into two groups: < 34 and ≥ 34 years, based on the median age of 34. Body mass index ($kg \cdot m^{-2}$) was categorised into three groups: 18.5–24.9 (normal), 25.0–29.9 (overweight), and 30.0–39.9 (obese). The duration of working as an IHP was divided into three categories: ≤ 10 months, 10–25 months, and ≥ 25 months. The number of sessions was categorised as ≤ 75, 75–150, and ≥ 150. In addition, a percentage change variable was generated by utilising the baseline and final measurements of PFT parameters. The fractional change was calculated as ((last value - first value) / first value)) and multiplied by 100 to derive percentage change.

STATISTICS

The analyses were assessed using the SPSS (Statistical Package for Social Sciences; SPSS Inc., Chicago, IL, version 25) software program. Descriptive data were reported as frequency (*n*) and percentage (%) for categorical variables, mean and standard deviation (SD) for continuous variables, and median with interquartile range (IQR) for continuous variables that were not normally distributed. The conformity of continuous variables to a normal distribution was evaluated by the Shapiro-Wilk test and visual methods (histograms and probability plots). The paired sample *t*-test was employed to assess the comparison between two dependent groups that conform to a normal distribution. In the independent two-group comparisons, the Student *t*-test was used for the data that had a normal distribution, and the Mann-Whitney U test was used for the data that did not conform to a normal distribution. In independent comparisons of more than two groups, the Kruskal-Wallis test was used for data that did not conform to a normal distribution. *Post-hoc* testing with Bonferroni correction (Mann-Whitney U test) was used for more than two significant within group comparisons. The analyses accepted a statistical significance level of $P < 0.05$ (in Bonferroni-adjusted Mann-Whitney U tests, $P < 0.017$).

Table 1
Descriptive data of inside attendants; SD – standard deviation

Parameter	*n* (%) or mean (SD) (min–max)
Gender	
Female	13 (92.9)
Male	1 (7.1)
Age (years)	33.7 (7.5) (22.0–45.0)
BMI ($kg \cdot m^{-2}$)	26.0 (3.4) (20.4–32.1)
Normal	5 (35.7)
Overweight	7 (50.0)
Obese	2 (14.3)
Smoking	
No	12 (85.7)
Yes	2 (14.3)
Smoking history (pack-year)	0.4 (1.2) (0.0–4.0)
Working duration (months)	25.4 (23.2) (6.0–92.0)
Number of sessions	141.4 (143.1) (30.0–579.0)
Number of sessions per year	83.3 (47.3) (15.0–154.0)

Results

Fourteen inside attendant healthcare personnel were included in the study. The medical records did not reveal any history of disease associated with pulmonary function. No sports activities that could have an impact on pulmonary function, including diving, were identified. All postero-anterior chest X-rays were normal. The descriptive data are presented in Table 1.

The most recent spirometry tests of IHP and their tests prior to working in hyperbaric oxygen therapy were compared. There was no statistically significant difference between the baseline and final measures for FEV_1, FVC, FEV_1/FVC, $FEF_{25–75}$, or PEF values ($P > 0.05$ for each comparison) (Table 2).

From the baseline and final measurements of PFT parameters, fractional and percentage changes were computed according to the formula given in the method section. The changes were compared based on gender, age, BMI, duration of working,

Table 2
Baseline and final spirometry tests values of inside attendants; $FEF_{25–75}$ – forced expiratory flow at 25%–75% of FVC; FVC – forced vital capacity; FEV_1 – forced expiratory volume at one second; PEF – peak expiratory flow; SD – standard deviation

Parameter		% of predicted Mean (SD)	*P*
FEV_1 (L)	Baseline	98.5 (13.2)	0.668
	Final	99.8 (11.6)	
FVC (L)	Baseline	94.1 (11.6)	0.619
	Final	96.0 (13.6)	
FEV_1/FVC (%)	Baseline	92.5 (6.1)	0.205
	Final	90.4 (5.7)	
$FEF_{25–75}$ ($L \cdot s^{-1}$)	Baseline	112.0 (30.4)	0.110
	Final	104.9 (23.5)	
PEF ($L \cdot s^{-1}$)	Baseline	93.1 (14.4)	0.972
	Final	93.3 (23.2)	

Table 3

Fractional changes (x100 for percentages) in spirometry tests parameters by categories; values annotated 'a' are significantly greater than 'b'; *Mann-Whitney U; **Kruskal Wallis; †Bonferroni corrected P value = 0.015; $FEF_{25–75}$ – forced expiratory flow at 25%–75% of FVC; FVC – forced vital capacity; FEV_1 – forced expiratory volume at one second; PEF – peak expiratory flow

Parameter	Fractional change				
	FEV_1	FVC	FEV_1 / FVC	$FEF_{25–75}$	PEF
	Median (min–max)	Median (min–max)	Median (min–max)	Median (min–max)	Median (min–max)
Gender					
Female	0.02 (-0.19–0.39)	0.02 (-0.16–0.57)	0.00 (-0.12–0.13)	-0.04 (-0.26–0.23)	0.06 (-0.36–0.33)
Male	0.02 (0.02–0.02)	0.11 (0.11–0.11)	-0.09 (-0.09–[-0.09])	-0.13 (-0.13–[-0.13])	0.13 (0.13–0.13)
*P**	0.901	0.172	0.172	0.385	0.535
Age (years)					
< 34 (*n* = 8)	0.03 (-0.06–0.39)	0.03 (-0.15–0.57)	-0.02 (-0.12–0.06)	-0.03 (-0.19–0.09)	0.05 (-0.36–0.24)
≥ 34 (*n* = 6)	-0.00 (-0.19–0.05)	-0.00 (-0.16–0.11)	-0.02 (-0.09–0.13)	-0.08 (-0.26–0.23)	0.06 (-0.32–0.33)
*P**	0.366	0.699	0.747	0.606	0.796
Body mass index					
Normal (*n* = 5)	0.03 (-0.05–0.39)	0.06 (0.02–0.57)	-0.07 (-0.12–0.01)	-0.01 (-0.19–0.09)	0.14 (-0.14–0.24)
Overweight or obese (*n* = 9)	0.02 (-0.19–0.11)	-0.04 (-0.16–0.11)	0.00 (-0.09–0.13)	-0.07 (-0.26–0.23)	0.06 (-0.36–0.33)
*P**	0,463	0.096	0.161	0.641	0.257
Working duration					
< 10 months (*n* = 4)	0.03 (-0.19–0.11)	-0.06 (-0.16–0.03)	0.0 (-0.04–0.01)	-0.02 (-0.09–0.09)	0.05 (-0.36–0.06)
10–25 months (*n* = 5)	-0.0 1 (-0.06–0.03)	0.04 (-0.11–0.08)	-0.03 (-0.07–0.13)	0.01 (-0.17–0.23)	0.19 (-0.20–0.33)
> 25 months (*n* = 5)	0.02 (-0.05–0.39)	0.05 (-0.04–0.57)	-0.08 (-0.12–0.01)	-0.13 (-0.26–[-0.04])	-0.14 (-0.32–0.14)
*P***	0.761	0.188	0.339	0.065	0.188
Number of hyperbaric sessions					
≤ 74 (*n* = 5)	0.02 (-0.06–0.11)	-0.11 (-0.15–0.08)	0.01 (-0.03–0.13)[a]	0.01 (-0.07–0.23)[a]	0.06 (-0.20–0.19)
75–150 (*n* = 5)	-0.01 (-0.19–0.03)	0.03 (-0.16–0.06)	-0.04 (-0.07–0.01)	0.02 (-0.17–0.09)	0.06 (-0.36–0.33)
≥ 150 (*n* = 4)	0.03 (-0.05–0.39)	0.08 (0.02–0.57)	-0.08 (-0.12–0.0)[b]	-0.16 (-0.26–[-0.10])[b]	0.00 (-0.32–0.14)
*P***	0.607	0.139	***0.041***	***0.038***†	0.873

and number of sessions. In the analyses performed according to the number of sessions, FEV_1/FVC showed a 1% increase over time in those with ≤ 74 sessions, a 4% decrease in those with 75–150 sessions, and an 8% decrease in those with ≥ 150 sessions ($P = 0.041$). Bonferroni-adjusted *post-hoc* analyses to determine the source of the difference did not identify any significant pairwise differences ($P > 0.017$ for each comparison). As for $FEF_{25–75}$, there was a 1% increase in those with ≤ 74 sessions and a 2% increase in those with 75–150 sessions, whereas a 16% decrease was observed in those with ≥ 150 sessions ($P = 0.038$). Bonferroni-adjusted post-hoc analyses showed a significant difference between those with ≤ 74 sessions and those with ≥ 150 sessions ($P = 0.015$) (Table 3).

During the follow-up period, no respiratory tract disease findings were observed in any IHP, aside from occasional cases of acute upper respiratory tract infections.

Discussion

In this study, we investigated whether there has been a longitudinal alteration in the lung function of healthcare professionals working in our centre since they began working as inside attendant for hyperbaric oxygen therapy. Percentage changes in predicted values showed no significant spirometry differences pre- and post-hyperbaric exposure, but greater session numbers were associated with a larger $FEF_{25–75}$ decline over time.

One study reported a substantial decline in FEV_1, $FEF_{25–75}$, and FEV_1/FVC values over time after retrospectively analysing 51 IHP over an average of 9.26 years.[7] Another study comparing the 1-year lung function of 11 IHP with a control group of fifteen participants found a significant decrease of 2.3% in the predicted FEV_1 and 3.7% in the $FEF_{25–75}$ in IHP within a year.[19] In contrast, no difference was noticed in comparison to a control group.[19] Similar to the latter study, we did not find any significant differences in PFT parameters. Because of our shorter follow-up duration and fewer IHPs, our study's results may differ from those of Poolpol et al.[7]

Demir et al. examined spirometry tests of 68 IHP with no previous HBOT experience before and after single hyperbaric sessions.[20] Mean FVC was 3.56 (SD 0.66) L before hyperbaric exposure and decreased by 3.4% to 3.44 (0.62) L after exposure. The mean FEV_1 was 3.37 (0.63) L before the session and 3.24 (0.59) L after the session; a 3.9% decrease. There was no statistically significant difference between the mean FEV_1/FVC ratio, PEF, and $FEF_{25–75}$ measurements before and after hyperbaric exposure. The authors suggested that the measured changes of less than 5% were not likely clinically relevant.[20] While the results of that study were based on a single HBOT session, they are consistent with our findings in that no changes likely to be clinically significant were found.

Most studies on respiratory function have primarily focused on divers. Previous research has demonstrated that divers tend to have larger lung volumes, a finding attributed both to natural selection and to the repetitive breath-holding and respiratory resistance encountered during diving.[8,21,22] However, studies examining the long-term spirometric measurements of IHP are limited. In a longitudinal study of 51 IHP with a follow-up period of 9.26 years, no significant changes in FVC, expressed as a percentage of the predicted values, were observed. While our study showed a slight increase in mean FVC over time, this change was not statistically significant.[7] It is well-established that FVC decreases with age in individuals without known pulmonary disease.[23] Although IHP may exhibit some degree of physiological adaptation to repeated hyperbaric exposures, the slower descent and ascent rates used during HBOT (1.5–2.0 $msw{\cdot}min^{-1}$) compared to standard diving practices (10–18 $msw{\cdot}min^{-1}$), and the absence of breathing masks during HBOT, may reduce the extent of this adaptation compared to divers. These factors may modulate the effects of hyperbaric exposure on the natural aging process, underscoring the need for further research in this area.

Several investigations have shown a decrease in expiratory flows at low pulmonary volumes, which may be attributed to pathological changes in the lung periphery.[24] For three years, Skogstad et al. monitored 87 divers at a diving school.[13] They found a significant decline in the mean FEV_1, $FEF_{25–75}$, and FEF_{75} of divers following this period. The authors concluded that diving could lead to changes in PFTs, mostly affecting small airway conductance and dysfunction. In another study Skogstad and Skare reported a decrease in $FEF_{25–75}$ after 12 years of diving.[25] Shopov conducted an analysis of spirometry test results in a group of 52 military divers and compared them to a control group ($n = 48$) consisting of deck crew who had similar physiological features.[26] The divers had an average of 10.2 (SD 2.5) years of diving experience. There was a statistically significant increase in FVC (both in percentage and absolute volume), a decrease in $FEF_{25–75}$ (again, both in percentage and volume), and a decrease in FEV_1/FVC. However, there were no significant changes in FEV_1 and PEF. Shopov concluded that diving can lead to PFT changes consistent with small airway obstruction.[26] Pougnet et al. showed that the FEV_1/FVC ratio and FEF_{25} decreased significantly after 15 years of professional diving.[27] Poolpol et al. also demonstrated that lung function alterations were associated with average working depths, session lengths, and total working hours.[7] Kangal et al. conducted a study involving 64 divers with an average diving experience of 13.6 (SD 7.3) years. They found that both the FEV_1/FVC ratio and $FEF_{25–75}$ were significantly decreased in these divers. Additionally, a noteworthy negative correlation was seen between the FEV_1/FVC ratio and both the $FEF_{25–75}$ and the number of years of diving experience. The authors concluded that occupational diving creates clinically asymptomatic changes in spirometry tests due to small airway obstruction after many years of exposure.[28] In our study, the percentage change in $FEF_{25–75}$ among inside IHP demonstrated statistically significant variations based on the number of HBOT sessions. Although the changes in FEV_1/FVC were not statistically significant, a trend was observed where those with a higher number of sessions exhibited greater reductions in both FEV_1/FVC ratio and $FEF_{25–75}$ values. However, no clinical symptoms related to pulmonary system disease were observed in any of the IHP.

The $FEF_{25–75}$ does not contribute additional information already provided by the FVC and FEV_1.[29] The infrequent occurrence of abnormal expiratory flows in the presence of normal FEV_1 and FVC values may indicate measurement 'noise'. This suggests that maximum mid-expiratory flow and flow towards the end of a forced expiratory maneuver add limited value to clinical decision-making.[29] The absence of clinical symptoms related to pulmonary system disease in the IHP in our study also supports this.

Contrary to the above studies, some studies conducted in recent years have not detected any changes in the pulmonary functions of divers.

In a longitudinal cohort study, 8,149 spirometry tests from 1,260 navy divers were analysed. Long-term pulmonary function changes in professional navy divers were found to be no different from those in the non-diving population.[17] In another longitudinal study, 232 divers with data spanning 10 to 25 years were analysed. The PEF showed a greater decline than expected for age in long-term divers and was significantly correlated with the duration of diving and initial age. However, these changes were considered small and clinically insignificant.[16] In our study, only $FEF_{25–75}$ showed a greater decline over time in those with a higher number of sessions compared to those with fewer sessions, but this change was also not clinically significant. However, the absence of clinical symptoms in IHP and the lack of significant differences in PFT changes other than $FEF_{25–75}$ may be due to the FVC manoeuvre not being performed correctly.

Inside attendants breathe compressed air during the HBOT session, an experience similar to that of divers. These sessions occur at a pressure similar to being 10–15 metres underwater. During compression, nitrogen diffuses into tissues; then during decompression, if the partial pressure of accumulated nitrogen in tissue exceeds ambient pressure (supersaturation), the dissolved nitrogen may form bubbles. These bubbles can pass in the venous blood to the pulmonary microvasculature where they may incite inflammation. Potential, but uncertain adverse effects on pulmonary function may result.[2,30] Based on our data, any related effects in IHP appear minor or physiologically inconsequential because no significant changes were observed in longitudinal PFT measurements.

LIMITATIONS

There are certain limitations to this study. Our study was retrospective; nearly all of the participants were women, and all of them were Caucasian. The number of participants in the study was small. This limits the ability to generalise the results. Moreover, future research could investigate confounding variables like contact with undiscovered allergens and high air pollution, which can be challenging to investigate.

Conclusions

This study demonstrated that IHP did not exhibit significant changes in overall lung function as a result of hyperbaric exposures, although a notable decline in $FEF_{25–75}$ was observed in those with a higher number of exposures. No clinically significant respiratory symptoms were identified in the study population. In the absence of changes in FEV_1, FVC, or PEF values, the observed decrease in $FEF_{25–75}$ could be the result of improper FVC manoeuvre performance. Given the critical role of IHP in HBOT sessions, maintaining their pulmonary health is essential. Ensuring the accurate execution of the FVC manoeuvre during assessments is thus important. Our findings suggest that hyperbaric exposure may not have a significant negative impact on pulmonary function in IHP. Further prospective studies are necessary to investigate the long-term clinical significance of these findings and to better understand the effects of hyperbaric exposure on respiratory function over time.

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