Chamber personnel's use of Nitrox 50 during hyperbaric oxygen treatment: A quality study – *Research report*

Marco B. Hansen [1,2], Tejs Jansen [1], Michael B. Sifakis [1], Ole Hyldegaard [1,2], Erik C. Jansen [1]

[1] Hyperbaric Unit, Department of Anesthesia, Centre of Head and Orthopedics, Copenhagen University Hospital, Rigshospitalet, Copenhagen, Denmark

[2] Laboratory of Hyperbaric Medicine, Department of Anesthesia, Centre of Head and Orthopedics, Copenhagen University Hospital, Rigshospitalet, Copenhagen, Denmark

CORRESPONDING AUTHOR: Dr. Marco B. Hansen – *Marco.Bo.Hansen.02@regionh.dk*

ABSTRACT

Objective: We aimed to evaluate the feasibility and safety of using Nitrox 50 as breathing gas during attendance in a multiplace hyperbaric chamber.

Methods: Paper logs between Jan.-Dec. 2011 were reviewed to analyze nitrogen gas-loading, actual bottom time, total bottom time and surface interval time. With the use of the Norwegian Diving Tables nitrogen gas-loading was converted to Repetitive Group Letters. Symptoms of decompression sickness and health problems related to hyperbaric exposures were registered at weekly staff meetings. The chamber personnel breathed chamber air or Nitrox 50.

Results: 1,207 hyperbaric exposures were distributed to five chamber attendants and technicians, 14 doctors, and six nurses. Nitrox 50 was inhaled on 978 occasions (81.0%). Median nitrogen gas-loading after first pressurization complied with Repetitive Group Letter A (range A-E), second to C (range A-F), third to D (range A-F), fourth to E (range C-H), fifth to F (range C-H), and sixth to E (range B-G). No symptoms of decompression sickness were reported (95% CI 0.00-0.33%).

Conclusion: Breathing Nitrox 50 during repetitive hyperbaric sessions seems to be feasible and safe while meeting high demands in number of treatment sessions and patient flow and with fewer people employed in the hyperbaric unit.

INTRODUCTION

The literature is very sparse regarding the risk of decompression sickness (DCS) and injuries related to hyperbaric exposures among the staff, yet rumors exist. The incidence of DCS in chamber personnel varies between hyperbaric units (Table 1, [1–5]). The highest incidence of DCS reported on a 2.4 atmospheres absolute (atm abs) table is 0.76% [6]. Through history there has been at least one death of an inside attendant from DCS [7]. In a recent questionnaire to 31 staff members using air as breathing gas, 51 complaints compatible with decompression stress were reported [5]. Ear barotrauma is probably the most frequent problem observed in hyperbaric attendants, but the incidence is unknown and the cases probably under-reported [3,8].

In many multiplace chambers a physician, nurse, or technician takes care of the patients. The personnel are typically breathing air during most of the treatment session, while oxygen is used as breathing gas during decompression to eliminate nitrogen from the body and reduce the risk of decompression sickness (DCS) [9]. The constellation of a multiplace chamber with a separate air lock compartment allows the hyperbaric staff to enter or leave the main chamber compartment when needed without decompressing the main chamber and thereby interrupting treatment of the patients. The advantage of this method is the possibility to provide short time exposures of the personnel to hyperbaric conditions, thus reducing the inherent risks of DCS [9]. Additionally, the short time exposures may be combined with the breathing of oxygen-enriched air (Nitrox), which reduces the nitrogen gas (N_2) load on the staff.

The only multiplace facility in Denmark (population of 5.6 million people) applies the operational principles of remotely operated vehicles for undersea exploration with the combination of dive principles and technology.

TABLE 1 – Review of published data on DCS rates in hyperbaric personnel with computed 95% confidence intervals

	Study period (months)	HBO_2 exposures (number)	Incidence of DCS (%)	95% CI (%)
Kluger [1]	120	5,792	0.07	0.03-0.18
Doolette, *et al.* [2]	36	1,531	0.20	0.07-0.58
Cooper, *et al.* [3]	168	6,062	0	0.00-0.06
Uzun, *et al.* [4]	120	4,532	0	0.00-0.08
Larsson, *et al.* [5]	16	1,808	0	0.00-0.21

HBO_2 – hyperbaric oxygen; DCS – decompression sickness; 95% CI – 95% confidence intervals

This implies that only necessary medical devices are utilized inside the chamber, while the remaining devices are controlled remotely from the outside. The personnel assist the patients during compression and exit the chamber during most of the treatment time. The personnel enter the hyperbaric chamber only when requested and for a minimum period of time. The approach allows for the hyperbaric exposure of the personnel to be kept to a minimum.

In 1998 in our hyperbaric department, the use of Nitrox 50 (50% oxygen and 50% nitrogen) as a breathing gas for attendants was introduced. The aim with the implementation of Nitrox 50 was to obtain a reduction of the N_2 load experienced by the personnel while treating difficult cases, thereby reducing the risk of DCS and N_2 narcosis. The risk of decompression sickness in medical attendants during hyperbaric oxygen (HBO_2) therapy limits compression bottom time of the chamber personnel and consequently reduces the treatment time of patients [5]. In theory, longer bottom time and shorter surface interval of the personnel should be possible by breathing Nitrox 50 compared to breathing ambient compressed air or Nitrox with a higher N_2 fraction. As long as the requirement for no decompression exposure has the highest priority, it should be possible to increase the treatment time of patients as well as the number of treatments performed with the same chamber personnel without jeopardizing the staff.

Accordingly, the aim of the study was to assess the feasibility and safety of breathing Nitrox 50 during attendance in a multiplace hyperbaric chamber. We hypothesized that the requirements of frequent repetitive pressurizations and a high patient flow set by a large and busy hyperbaric unit can be met by the use of a Nitrox 50 protocol while keeping the N_2 load (primary end point) in a small group of chamber personnel within accepted safety limits. Additionally, no symptoms of DCS or serious adverse events would appear.

METHODS

Data collection

Data was collected prospectively and comprised the paper logs documenting each hyperbaric treatment performed at Rigshospitalet between January and December 2011. Body N_2 loading from the first hyperbaric exposure – depending on actual bottom time (ABT) – was estimated with the use of the Norwegian Diving Tables and expressed as a letter from A to Z [10]. Letter A represented the lowest and Letter Z the highest level of residual nitrogen in the chamber personnel's body. For any subsequent hyperbaric exposures the letter representing the N_2 load of the personnel in question, were then translated into a Repetitive Group Letter depending on the surface interval time (SIT) calculated in minutes between the hyperbaric exposures. In 1998 a safety organization was established in our hyperbaric unit, which included a weekly staff meeting. At these meetings symptoms of DCS and work-related health sequelae were discussed and reported in writing. The meetings held in 2011 were reviewed in order to find symptoms of DCS and work-related health sequelae.

Study subjects

The chamber personnel were subject to the safety evaluation and consisted of a multidisciplinary team that included attendants, technicians, doctors and nurses. Each group of employees could be pressurized. The system for choosing the group of employees assisting patients during compression was as follows: The attendants were planned to assist the patients. Only in cases where the condition of the patient deteriorated or advanced treatment was necessary would a doctor enter the chamber. If the attendants reached a high level of N_2 loading the nurses or technicians would be compressed. The attending doctors were specialized in anesthesiology and intensive care medicine. The attendants and technicians were experienced professional divers specifically trained to handle the equipment and operate the hyperbaric chamber. There was a 24-hour rotation schedule between attendants and technicians.

The nurses were present in the hyperbaric unit in daytime. The primary role of the nurses was to care for the physical and psychological health of the often chronically ill patients for whom sequelae after radiation therapy were the most predominant indication for HBO_2 therapy. All chamber personnel had an annual medical examination either as recreational divers or by an approved diving physician.

Working environment, hyperbaric exposure protocol and breathing gas profile

The treatment protocols were devised according to the guidelines of the Undersea and Hyperbaric Medical Society, the European Committee of Hyperbaric Medicine and from our clinical experiences. Patients and chamber personnel were pressurized in a multiplace hyperbaric chamber (Drass Galeazzi Underwater Technology, Italy) with a capacity of seven sitting patients or one patient in intensive care. The intensive care was supported by a ventilator (Siaretron 1000 IPERTM, Siare, Bologna, Italy) and infusion pumps. Compression was performed to a therapeutic pressure typically at either 2.4 atm abs or 2.8 atm abs in 90 minutes depending on treatment indication. Compression and decompression times were set to five minutes. In situations where patients were treated for decompression sickness or arterial gas embolism, Norwegian standard Treatment Table 5 or 6 was used [10].

Nitrox 50 was the recommended main breathing gas. If the personnel had to access the chamber quickly, ambient compressed air would primarily be breathed. Nitrox 50 was breathed through masks (Divex Ultralite 2 BIBS Mask, Divex Ltd., Aberdeen, U.K.). When personnel breathed Nitrox 50 at 2.4 atm abs or 2.8 atm abs, the 9 Meters Standard Air Decompression Table was used for table-based equivalent N_2 burden [10]. When personnel breathed chamber air at 2.4 atm abs or 2.8 atm abs, the 15 meters and 18 meters Standard Air Decompression Tables were used, respectively. According to the recommendations at the hyperbaric unit, chamber personnel should not exceed maximum no-decompression bottom time, thereby always allowing for the direct decompression to normobaric pressure. In practice, this means an N_2 penalty corresponding to Letter group H at 15 meters depth and Letter group I at 18 meters depth, regardless of breathing gas. For practical and safety reasons we accept N_2 loading corresponding to Letter G. The group G permits at least 20 minutes in reserve before decompression stops are necessary. There was no observed deviation from the standard protocol or existing safety procedures in the study period.

Outcomes

The primary outcome was N_2 loading as defined by the Norwegian Diving and Decompression Tables [10]. Secondary outcomes were signs and symptoms of DCS as well as any other sequelae related to hyperbaric exposures. Furthermore, actual bottom time (ABT), total bottom time (TBT, consistent with equivalent single dive time, ESDT, in USN terminology), and surface interval time (SIT) of the chamber personnel were assessed. ABT was defined as the elapsed time in minutes from the beginning of compression to the beginning of decompression. TBT was defined as the sum of the residual N2-time from previous pressure exposure and the ABT. SIT was defined as the elapsed time spent from ended treatment until the next compression.

Statistical analysis

Numeric data are expressed as mean and standard deviation or median and range when appropriate. Qualitative data are expressed as frequency and percentage.

RESULTS

Treatments

No paper logs were excluded. During the study period 1,075 hyperbaric treatment sessions were performed with 4,282 patient treatments registered. The hyperbaric treatments were distributed in 788 (73.3%) elective treatment sessions and 287 (26.7%) acute treatment sessions. Patient treatments were distributed as 3,907 (91.2%) elective patient treatments and 375 (8.8%) acute patient treatments. In 118 (11.0%) treatment sessions no chamber personnel were pressurized during the treatment and, of these, 111 cases (94.0%) were acute treatments with critically ill patients. In 162 (56.5%) acute sessions the patients were treated with ventilator and required extensive hemodynamic monitoring.

TABLE 2 - Main characteristics and exposure profiles of the chamber personnel

	Attendants (n = 5)	Technicians (n = 5)	Doctors (n = 14)	Nurses (n = 6)
Male gender (n)	5	5	10	1
Age, years (range)	47.2 (40-53)	47.2 (40-53)	50.0 (41-68)	50.5 (44-64)
BMI (kg/m2)	28.4 (4.8)	28.4 (4.8)	25.1 (3.2)	25.1 (4.5)
Number of hyperbaric exposures in 2011 (%)	984 (81.6)	40 (3.3)	92 (7.6)	91 (7.5)
Mean exposures/day (SD)	2.70 (1.7)	0.11 (0.4)	0.25 (0.6)	0.25 (0.6)
Use of nitrox (%)	868 (88.2)	13 (32.5)	24 (26.1)	49 (53.9)
DCS incidence, 2011, % (95% CI)	0 (0.00-0.39)	0 (0.00-8.76)	0 (0.00-4.01)	0 (0.00-4.05)
Estimated hyperbaric exposures, 1998-2011 (%)	33,868 (81.6)	1,380 (3.3)	3,171 (7.6)	3,137 (7.5)
Estimated DCS incidence, 1998-2011, % (95% CI)	0 (0.00-0.01)	0 (0.00-0.29)	0 (0.00-0.12)	0 (0.00-0.13)

SD – standard deviation; n – number of subjects; 95% CI – 95% confidence interval; BMI – body mass index; DCS – decompression sickness

Study subjects

The subjects comprised five chamber attendants and technicians (identical persons), 14 doctors, and six nurses. Characteristics of the personnel are summarized in Table 2. 1,170 pressurizations of the personnel with a total of 1,207 hyperbaric exposures were performed. Of these, 1,133 (96.9%) pressurizations were performed with only one personnel inside the chamber. In 37 cases (3.1%) two staff members were required inside the chamber at the same time to take adequate care of the patients.

Nitrogen gas loading

The N_2 loading of the attendants, technicians, doctors, and nurses breathing either Nitrox 50 or ambient compressed air is expressed in Figure 1. During the study period attendants were pressurized 984 times (81.6%) with a mean of 103 pressurizations per 100 sessions. The group of doctors had 92 compressions (7.6%) with a mean of 10 compressions per 100 sessions. The nurses were pressurized 91 times (7.5%) during the study period corresponding to 10 pressurizations per 100 sessions. Technicians had 40 pressurizations (3.3%) with a mean of four pressurizations per 100 sessions. We observed that the attendants were the group of personnel being pressurized most frequently during a shift and as a result had the highest N_2 loading *(Figure 1)*. In one case an attendant was pressurized seven times with N_2 loading complying with Letter G. One time an attendant reached Letter H after the fourth compression and one time after the fifth compression *(Figure 1)*. Technicians were pressurized the fewest times, which is consistent with their work function. As a result they had the lowest body N_2 load. The doctors and nurses were almost equally exposed. Throughout the pressurizations all groups of personnel retained a relatively low N_2 load despite a great workload.

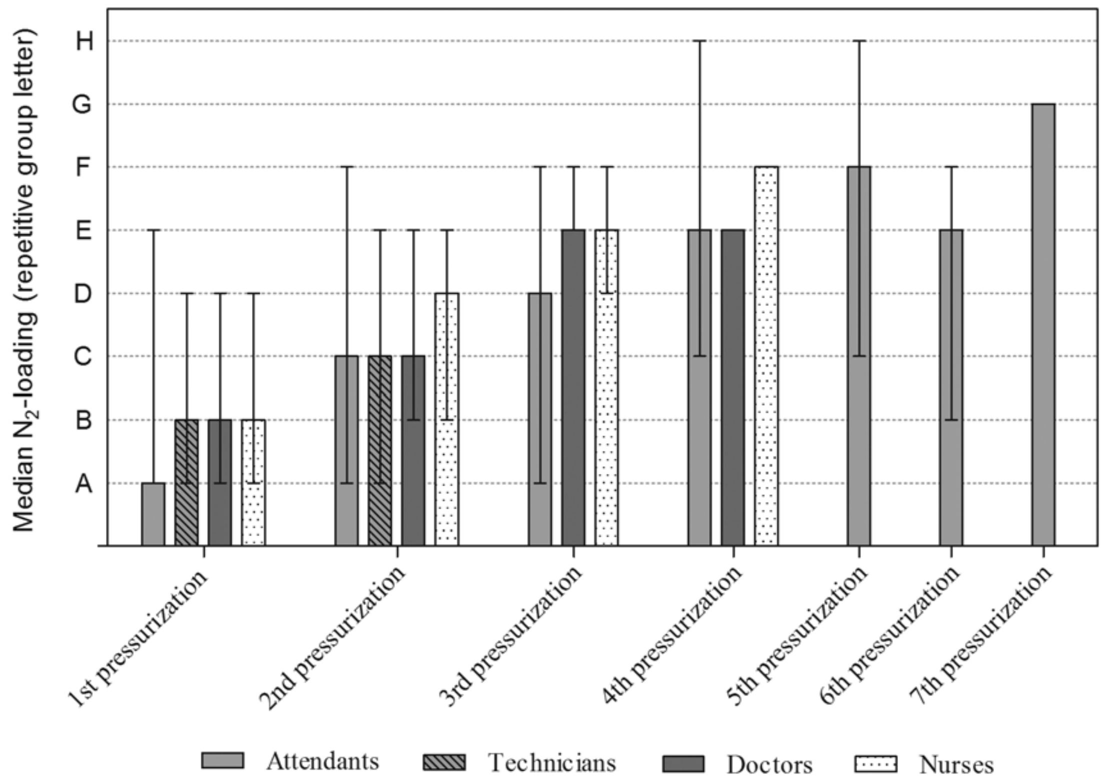
Actual bottom time, total bottom time, and surface interval time

The exact means of ABT, TBT and SIT for each group of staffing related to the pressurizations are showed in Table 3. The mean ABT of the attendants was nine minutes (SD ± four minutes). The results showed that the attendants, together with the nurses, had the longest ABT and TBT *(Table 3)*. This is in line with the relatively low N_2 loading observed in both groups. Together with the technicians, the doctors had the lowest mean ABT and mean TBT *(Table 3)*.

Breathing gas profile, pressure protocol and decompression sickness

In total, Nitrox 50 was breathed on 978 occasions (81.0%). Nitrox 50 was used as breathing gas in 831 (86.5%) pressurizations performed during the elective treatments, while Nitrox 50 was used as breathing gas in 139 (56.5%) acute pressurizations. The attendants used Nitrox 50 in 88.2% of the cases, the technicians in 32.5% of the cases, the doctors in 26.1% of the cases, and the nurses in 53.9%. In all other cases atmospheric air was used as the breathing gas. In 1,023 cases (79.4%) the personnel were pressurized to 2.4 atm abs and in 235 cases (18.2%) to 2.8 atm abs. In one case (0.1%) the Norwegian standard treatment table 5 (2.8 atm abs) was used, and in 29 cases (2.3%) the Norwegian standard treatment table 6 (2.8 atm abs) was used. There

FIGURE 1 - Acumulated N_2 loading



Accumulated N_2 loading of personnel after each pressurization expressed as Repetitive Group Letters [10].
Data are presented as median (range). Letter A represents the lowest and Letter H the highest level of residual N2 in the chamber personnel's body after ended pressurization.

TABLE 3 - Mean ABT, TBT, and SIT measured in minutes during pressurizations performed by attendants, technicians, doctors and nurses

	ABT, min				TBT, min				SIT, min			
No. press**	AT	TE	DC	NU	AT	TE	DC	NU	AT	TE	DC	NU
First	10 (3)	6 (4)	6 (4)	9 (4)	10 (3)	7 (5)	6 (4)	10 (4)	112 (85)	185 (298)	56 (62)	88 (74)
Second	9 (4)	6 (4)	6 (5)	9 (3)	27 (7)	16 (8)	19 (8)	28 (5)	106 (62)	4 (0)	20 (6)	65 (52)
Third	10 (4)	*	6 (4)	8 (6)	46 (10)	*	31 (4)	48 (7)	125 (89)	*	114 (0)	132 (0)
Fourth	9 (5)	*	6 (0)	8 (0)	52 (16)	*	31 (0)	63 (0)	130 (105)	*	*	*
Fifth	8 (3)	*	*	*	56 (21)	*	*	*	212 (152)	*	*	*
Sixth	8 (4)	*	*	*	43 (13)	*	*	*	11 (0)	*	*	*
Seventh	13 (0)	*	*	*	43 (0)	*	*	*	*	*	*	*

Data are mean (standard deviation). ABT – actual bottom time, minutes. TBT – total bottom time, minutes.
SIT – surface interval time, minutes. AT – attendants. TE – technicians. DC – doctors. NU – nurses. Min – minutes.
* No pressurizations performed.
**Number of pressurizations during a shift: Attendants 24 hours, technicians 24 hours, doctors between 8-16 hours, nurses 8 hours.

were no recorded cases of DCS among the chamber personnel (95% confidence interval [CI] 0.00-0.33% incidence of DCS). Other sequelae related to treatment protocol and pressurizations such as ear barotrauma was not reported over this one-year period.

DISCUSSION

We are, to the best of our knowledge, the only hyperbaric unit that systematically uses this hyperbaric exposure protocol and the first to evaluate the safety of Nitrox 50 as breathing gas for chamber personnel measured by N_2 loading. According to our local recommendations, critically ill patients do not require the presence of a nurse or doctor inside the chamber, which gives a different aspect to the safety of the inside chamber personnel. The doctor or the nurse, however, is supposed to reach the patient within less than 30 seconds if necessary. This is assumed to equal the actual conditions in other intensive care units.

Nitrogen gas loading and pressurization profiles

The majority of the research regarding safety in the hyperbaric environment focuses on the patients. However, the occupational health and safety of personnel is an important issue for the society of hyperbaric units and is still highly relevant [11]. The Danish Agency for Safety and Health at Work considers working in a hyperbaric unit to be particularly risky, rating it as one of the 10 most dangerous areas of profession in the country [12].

When using Nitrox 50 the equivalent depth on the diving table is 9 meters at 2.4 atm abs and 12 meters at 2.8 atm abs. The exposure time to the point where a safety stop is required during decompression to normobaric ambient air is thereby more than 450 minutes at 2.4 atm abs and 135 minutes at 2.8 atm abs [10]. The results showed that only when the personnel were pressurized four to seven times within a 24-hour shift did they reach the maximum limit of N_2 loading. In these cases, the personnel used only half of the time for the no-decompression limit and thereby still retained the option of direct decompression to normobaric ambient air. Even though the attendants reached Letter H in two cases and thereby exceeded the agreed maximum N_2 loading, the safety margin is large and equivalent to at least 45 minutes of pressure exposure time at 2.4 atm abs before a safety stop is needed. The observations emphasize a high degree of theoretical safety that is obtained by using our Nitrox 50 protocol. In addition, we used a conservative approach when calculating the N_2 loading. Even if air was breathed a single time the entire pressurization was considered an "air dive."

In the group of attendants we found a marked increase in TBT during the pressurizations, which reflects the increase in residual N_2 time from the previous exposures *(Table 3)*. It can be seen that TBT and thereby N_2 time and N_2 load are markedly increased when the attendants are being pressurized three times or more during a shift. The mean SIT was highest for the attendants (116 minutes, *Table 3*). This probably reflects the long work shifts of the attendants (24 hours) compared to 16 and 8 hours for the doctors and nurses, respectively. However, the time between pressurizations remained low, which demonstrates that frequent repetitive pressurizations can be performed without the need of changing in-chamber personnel.

From a healthcare and safety perspective, the daily staff should be clinical experts. To become an expert, formal training as well as clinical experience is necessary. However, in hyperbaric medicine the expert role is difficult to achieve because of few patient treatments or many employees at the hyperbaric unit. The Nitrox 50 protocol allows fewer employees in the hyperbaric unit with the possibility of several pressurizations. Along with the high number of pressurizations come increased education, experience and clinical competencies among the personnel. In addition, patients will receive treatments by the same chamber personnel who know and follow them over time. This may optimize patient comfort and treatment compliance.

The hyperbaric unit has had a substantial increase in workload and in number of patient treatments over the years. The Nitrox 50 protocol has made it possible to maintain the same amount of personnel, which not only has an advantage regarding the clinical expertise, but also in economic terms.

In 111 out of 287 acute treatments with critically ill patients, no chamber personnel were inside the chamber at any point during treatment. This was possible due to the small volume of our entry and exit hatch. Should any emergency arise, patients can be reached within 22 seconds without decompressing the main chamber. No equalization problems in ears or sinuses appeared in the attendants, nurses or physicians during the fast pressurizations.

Decompression sickness and other work-related sequelae

To avoid DCS, the chamber attendants in our center follow standard protocols specific to the hyperbaric unit in Copenhagen. During the study period we found neither major nor minor symptoms of DCS among the different groups of staffing (95% CI 0.00-0.33%, *Table 2*). In fact, during the 15 years of the department's existence there have not been any reported cases of DCS or symptoms related to DCS even though regular weekly safety meetings were held during the period. From 1998-2011 the department has performed 37,011 treatment sessions. As can be seen from the study period in 2011 we experienced 1,207 pressurizations of the personnel during 1,075 treatment sessions, which gives a mean of 1.12 pressurizations pr. treatment session. Based on this information and since the working routines have not changed markedly during the 15 years, we can make an estimate of the total number of HBO_2 exposures resulting in 41,556 exposures (95% CI 0.00-0.01%). The estimated numbers of HBO_2 exposures and incidences of DCS related to each staffing group during the 15-year period is expressed in Table 2. It seems that DCS can be reduced to near-zero levels by the adoption of this conservative Nitrox protocol without the need of decompression strategies and preventive oxygen-breathing periods.

Only two times in the history of the center have personnel complications related to pressurizations been observed. In both cases doctors had sinus problems. As can be seen from the relative low number of incidents, this is not a frequent problem and has never been an issue during emergency decompressions. However, should sinus problems occur during the fast pressurizations, another member of the personnel has to be pressurized, and such a problem will cause only a minor delay in the time to reach the patient. Another possibility is to make a direct decompression of the chamber to normobaric pressure. This can be done rapidly as a result of treatment sessions without in-chamber personnel.

When using Nitrox 50 the equivalent partial pressure of inspired oxygen (PiO_2) are 1.2 and 1.4 atm abs at a chamber pressure of 2.4 and 2.8 atm abs, respectively. The safety limit for PiO_2 is 1.6 atm abs during these pressures [10]. Therefore, we operate with oxygen pressures low enough to provide adequate protection of the personnel against acute oxygen toxicity. This is supported by the results of the attendants being exposed the most and repeatedly, but did not experience mild pulmonary symptoms such as substernal discomfort. Based on empirical data, the chronic oxygen impact on the lungs can be calculated in Units of Pulmonary toxicity dose (UPTD). The maximal oxygen load is 45 minutes at a treatment pressure of 2.8 atm abs and provides an inspiratory oxygen pressure at 1.4 atm abs, which is equivalent to 2.35 UPTD per minute. Totally, this means a daily load of 105 UPTDs. In a further developed approach, designated the Repex method, the lowest total permitted daily load is 300 units per day [13]. Therefore, the daily load is not a risk for personnel.

Nitrox 50

Owing to the reduced fraction of inspired N_2, the uptake of N_2 into the body tissues during NitrOx 50 breathing is less than air breathing of the same time and pressure. Not only is the risk of DCS decreased, but also the narcotic effect of N_2 is theoretically minimized. This may be of importance when physicians have to make decisions inside the chamber [8]. Whether it plays an important role during therapeutic sessions at 2.8 atm abs is questionable. In addition, the dangerous side effects of N_2 accumulation are reduced with our relative short pressurizations of the personnel. Larsson, *et al.* demonstrated that when using Nitrox 60.5 at 2.8 atm abs, bottom time was increased when compared to working at the same pressure with ambient compressed air as breathing gas [5]. Neither DCS preventive oxygen-breathing periods (FiO_2 = 1.0) nor oxygen toxicity preventive air-breathing periods (FiO_2 = 0.21) are necessary with the applied protocol. Overall, no adverse events were experienced given the N_2 exposures reported, and the occupational health and safety of the chamber personnel seem to be respected with the Nitrox 50 protocol during repetitive pressurizations.

The large difference in the utilization of Nitrox 50 observed between the attendants and the other staff groups *(Table 3)* reflects the different tasks each group may perform during patient treatment. The attendants primarily assist the patients during compression in the elective treatments where communication and time factors do not play a critical role. In the acute settings with deteriorated and confused patients, the doctors need to be pressurized. Here, a fast pressurization and a clear communication with the patient are essential, which is why some doctors choose not to apply the Nitrox mask. The main reason for the attendants, technicians and nurses not to use the mask is due to communication difficulties with patients having impaired cooperation abilities.

Study limitations

The study was designed to investigate the feasibility and safety of a Nitrox 50 protocol when applied in a hyperbaric unit with frequent pressurizations and does not compare the N_2 load between different types of breathing gases. The risk of DCS is anticipated to be low when using the Nitrox 50 protocol and cannot be addressed by the small number of exposures reported here. The study focuses only on clinical symptoms and cannot be used to estimate the amount of bubbles in the blood or tissues. Reports have found that chamber personnel are exposed to significant decompression stress when pressurized to therapeutic pressures at 2.4 atm abs [14,15]. In addition, bubbles are detectable in 44% of the personnel at exposures of 2 atm abs and in 68% of exposures at 2.8 atm abs [16]. However, detection of bubbles does not correlate with the clinical symptoms of DCS [17]. Future studies with more standardized experimental conditions are needed. However, this study provides information regarding the clinical use of Nitrox 50 for hyperbaric personnel and may act as template when organizing a hyperbaric unit in the future.

CONCLUSION

Nitrox 50 permits a relatively small group of chamber personnel to perform the necessary tasks to take adequate care of the patients in a hyperbaric unit with a high patient flow and still remain within the no-decompression limits. The highest N_2 load was found to be Group H, equivalent to at least 45 minutes before a safety stop is needed. Neither symptoms of DCS (95% CI 0.00-0.33%) nor serious adverse events were registered. With this protocol the personnel enter the chamber only when needed and the risk of oxygen seizures, pulmonary toxicity and DCS is minimal. It seems to be feasible and safe for the chamber personnel to use a Nitrox 50 profile when working at pressures up to 2.8 atm abs.

Acknowledgments

The authors thank the entire staff in the Hyperbaric Unit, Department of Anesthesia, Centre of Head and Orthopedics, Copenhagen University Hospital, Rigshospitalet, Copenhagen, Denmark.

The authors report no conflict of interest with this submission.

■

REFERENCES

1. Kluger M. Implications of hyperbaric medicine for anesthesia and intensive care: part 1. SPUMS J. 1997;27:2–11.
2. Doolette D, Goble S, Pirone C. Health outcome of hyperbaric chamber inside attendants following compressed-air exposure and oxygen decompression. SPUMS J. 2004; 34:63–7.
3. Cooper PD, Van den Broek C, Smart DR. Hyperbaric chamber attendant safety II: 14-year health review of multiplace chamber attendants. Diving Hyperb Med. 2009;39:71–6.
4. Uzun G, Mutluoğlu M, Ay H, Yildiz S. Decompression sickness in hyperbaric nurses: retrospective analysis of 4500 treatments. J Clin Nurs. 2011;20:1784–7.
5. Larsson AC, Uusijärvi J, Frånberg O, Eksborg S, Lindholm P. Nitrox permits direct exit for attendants during extended hyperbaric oxygen treatment. Undersea Hyperb Med. 2012;39:605–12.
6. Brattebø G, Aanderud L, Risberg J, Thorsen E, Forland M. Incidence of decompression illness among HBO_2 nurses (Abstract). Zdrav Vestn. 1997;66:17A.
7. Hyperbaric chamber nurse dies of decompression sickness; unit gets OK. Hosp Secur Saf Manage. 1992;13:3.
8. Ledingham IM, Davidson JK. Hazards in hyperbaric medicine. British Medical Journal. 1969;3:324.
9. Vann RD, Butler FK, Mitchell SJ, Moon RE. Decompression illness. Lancet. 2011;377:153–64.
10. Arntzen A, Eidsvik S, Risbjerg J. Norske dykke- og behandlingstabeller (Norwegian Diving and Treatment Tables). 3rd ed. Loddefjord Norway: Barotech AS; 2008.
11. Johnson-Arbor K. Type II DCS in an inside hyperbaric attendant. Undersea Hyperb Med. 2012;39:915–9.
12. Arbejdstilsynet (The Danish Agency for Safety and Health at Work) C. Bilag 1 - Liste over særligt farligt arbejde (Appendix 1 - List of particularly hazardous work) [Internet]. Arbejdstilsynet, bekendtgørelser. [cited 2012 Sep 21]. Available from: http://arbejdstilsynet.dk/da/regler/bekendtgorelser/b/bygge-og-anlaegsarbejde-1516/bilag-1.aspx
13. Joiner J. NOAA Diving Manual: Diving for Science and Technology. 4th ed. Flagstaff, USA: Best Publishing Company; 2001:3-25.
14. Risberg J, Englund M, Aanderud L, Eftedal O, Flook V, Thorsen E. Venous gas embolism in chamber attendants after hyperbaric exposure. Undersea Hyperb Med. 2004;31:417–29.
15. Cooper PD, Van den Broek C, Smart DR, Nishi RY, Eastman D. Hyperbaric chamber attendant safety I: Doppler analysis of decompression stress in multiplace chamber attendants. Diving Hyperb Med. 2009;39:63–70.
16. Walker M, Capps R, Pirone C, Ramsay R. Doppler detection of circulating bubbles in attendants, decompressed on oxygen, following routine hyperbaric treatments. SPUMS J. 1995;35:62–4.
17. Walker M. Doppler bubble detection after hyperbaric exposure. SPUMS J. 1996;26:146–54.

✦