Hyperbaric chamber attendant safety II: 14-year health review of multiplace chamber attendants

P David Cooper, Corry Van den Broek, David R Smart

Key words
Decompression sickness, barotrauma, ear barotrauma, hyperbaric facilities, nursing, occupational health

Abstract
(Cooper PD, Van den Broek C, Smart DR. Hyperbaric chamber attendant safety II: 14-year staff health review of multiplace chamber attendants. *Diving and Hyperbaric Medicine*. 2009;39(2):71-6.)
Introduction: The multiplace hyperbaric chamber provides a unique working environment for health-care personnel. The major foci of concern regarding staff health under these conditions have tended to be decompression sickness (DCS) and barotrauma. Incidences of DCS as high as 1.3% have been reported in hyperbaric attendants exposed to routine treatment tables. Occupational health risks of this magnitude are not acceptable in routine clinical practice. Significant variations in procedures exist between institutions in an attempt to enhance staff safety. In extreme cases the use of multiplace chambers has been abandoned.
Aim: To determine the actual incidence of work-related health issues amongst attendants at a full-time clinical hyperbaric unit.
Methods: Design: retrospective staff health survey. Facility: university teaching hospital. Subjects: 155 medical, nursing and technical staff routinely exposed to hyperbaric conditions.
Results: There were no cases of DCS encountered in 6,062 attendant exposures, across all hyperbaric profiles, during this 14-year period (95% CI 0, 0.06%). Twenty-eight work-related injuries occurred during this time (0.46%), of which 25 (0.41%) were hyperbaric-specific.
Conclusion: A multiplace hyperbaric chamber can be viewed as a relatively safe working environment.

Introduction

The multiplace hyperbaric chamber provides a unique working environment for health-care personnel. The exposure of attendant staff to environmental conditions of increased ambient pressure and various inhaled gas mixtures during the performance of their duties is unmatched elsewhere in the health-care industry. Traditionally the most prominent focus of concern regarding staff health under these conditions has been decompression sickness (DCS), with barotrauma coming a distant second. Rates of DCS up to 0.76% have been reported in hyperbaric attendants exposed to routine 243 kPa (14 metres' of sea water (msw), 2.4 ATA) treatment tables, with higher rates reported for deeper tables.[1–3] This level of injury is not acceptable in today's workplace and significant variation in procedures, therefore, may be found between institutions in an attempt to enhance staff safety. As an example, within Australian and New Zealand hyperbaric units, bottom times for 243 kPa hyperbaric treatment tables, vary from 90 to 105 minutes and decompression times from 10 to 30 minutes; with both linear and staged decompression profiles being used (Figure 1).

The 243 kPa treatment table currently in use at the Royal Hobart Hospital (RHH) was first implemented in January 1997. Conservative decompression procedures were empirically chosen to ensure more than triple the recommended DCIEM Air Diving Tables' decompression time.[4] Oxygen breathing by the attendants was added for the duration of the decompression phase as an additional aid to nitrogen off-gassing. Doppler ultrasound evaluation of attendants exposed to this institution-specific table has demonstrated low levels of decompression stress.[5] With a zero incidence of clinical DCS and low levels of sub-clinical decompression stress evident from that study, we decided to review other health issues potentially attributable to working in the hyperbaric environment.

Aim

To determine the incidence and severity of work-related health issues amongst personnel exposed to increased pressure at a full-time clinical hyperbaric unit.

Methods

STUDY DESIGN

A comprehensive review of the on-site medical records of all hyperbaric attendants to have worked in this facility since the year prior to its commissioning (together, where appropriate, with individual interviews and cross-referencing against other sources of medical information) was performed. These records covered a 14-year period from January 1992 to December 2005. The chamber dive-log and computer database (in which the hyperbaric technical officers independently record any variances to standard pathways) were also searched for evidence of incidents that might not have resulted in an entry in the medical records. The project was approved by the relevant institutional ethics committee.

SUBJECTS

The records of all nursing, technical and medical staff working in the hyperbaric environment at RHH during the study period were reviewed. There were no exclusion criteria. Staff members undergoing hyperbaric exposure were all medically certified fit-to-dive in accordance with the appropriate Australian Standard in force at the time. Staff under the age of 40 years are re-certified biennially and those 40 years and over are re-certified annually. These obligatory medical examinations are performed in-house by hyperbaric physicians and the records retained on-site indefinitely. It is departmental policy for all general health-related issues to be reported and included in this record, together with any symptoms arising within 24 hours of hyperbaric exposure.

Baseline demographic data were collected for all eligible staff. These data included age, sex, height, weight and calculated body mass index (BMI), and the frequency with which they underwent hyperbaric exposure (Table 1).

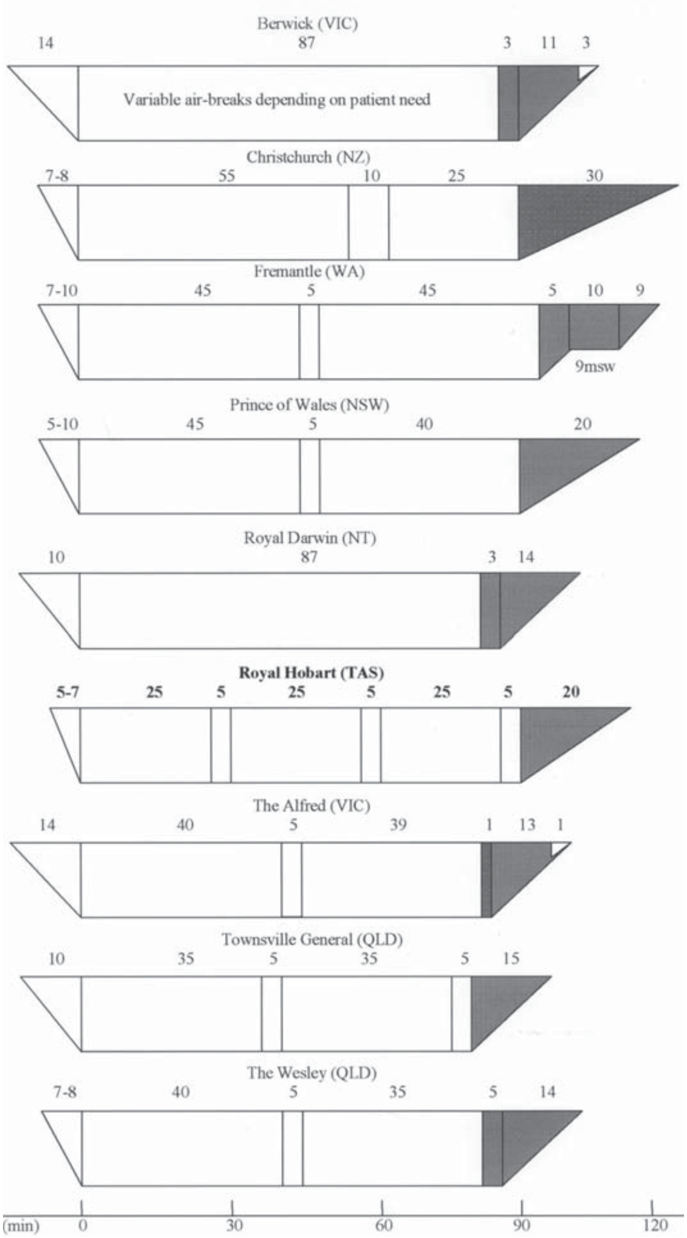
HYPERBARIC PROCEDURES

All exposures took place in the RHH multiplace chamber (Hydro Electric Commission, Hobart, Tasmania, 1993) – a 28-cubic metre, double-lock, cylindrical facility with a maximum operating pressure of 608 kPa. Established treatment tables (e.g., the 'RHH 14:90:20', Royal Navy treatment table 62 (RN 62) / US Navy treatment table 6 (USN 6), 'Comex 30', etc) accounted for the majority of hyperbaric exposures. Any non-standard exposure profiles (e.g., for training purposes) were conducted in accordance with DCIEM Air Diving Tables.[4] Oxygen (O_2) was used by attendants for the duration of all decompressions. If a patient required extensions on RN 62/USN 6, the attendant's O_2 breathing was extended to include the duration of the patient's final O_2 period at 182 kPa (i.e., the attendant received 90 minutes on O_2).

Personnel were routinely restricted to a maximum of four hyperbaric exposures per week, with no more than three consecutive days of pressure exposure. For most treatment tables a minimum 18-hour break was required between hyperbaric exposures to ensure attendants had returned to DCIEM repetitive factor 1.0 (i.e., no residual nitrogen load) prior to their next dive.[4] Following longer or deeper tables (e.g., RN 62/USN 6, Comex 30) this was extended to 48 hours.

Flying was forbidden for 24 hours after the attendant's last hyperbaric exposure. Additionally because of Hobart's mountainous terrain (highest habitation 550 m, routine attendant travel to >600 m, sealed roads to 1,250 m), attendants living >300 metres above sea level were required to remain at sea level for a minimum of four hours before travelling home. In practice, these staff were rostered for the morning treatment, allowing off-gassing in the afternoon.

Figure 1
Australasian 243 kPa (14 msw) chamber attendant tables – valid at November 2008
White = attendant on air. Grey = attendant on oxygen; patient air-breaks marked to indicate periods of increased chamber attendant activity in-chamber



Results

A total of 155 nursing, medical and technical staff underwent 6,062 hyperbaric exposures during 5,821 chamber pressurizations between January 1992 and December 2005. Medical records were available for 142 (92%) of these individuals. The chamber was under pressure for 10,895 hours during this time. Hyperbaric exposure profiles are summarized in Table 2.

There were no recorded cases of DCS amongst the chamber attendants over this 14-year period (95% CI 0.00, 0.06% incidence of DCS).

Review of the medical and technical records during this period revealed 28 potentially work-related health incidents (0.46%), of which 25 (0.41%) were hyperbaric-specific (Table 3). The most common complaints were of a minor ENT nature, with fifteen (1 in 400 compressions) minor to moderate middle-ear barotrauma episodes involving eighteen ears (nine Teed-Edmonds Grade O, five Grade I and four Grade II), one external ear barotrauma related to a plug of cerumen and three episodes of sinus squeeze on descent. One episode of sinus squeeze and eleven of middle-ear barotrauma were associated with recent upper respiratory tract infections (URTI). Five of these episodes of middle-ear barotrauma resulted in the attendant aborting the dive during pressurization (at 110–200 kPa).

Three episodes of odontalgia and one of obvious dental barotrauma (all associated with old dental work) occurred. Restorative dental work was paid for by the hyperbaric unit in the case of obvious dental barotrauma, with the attendant self-funding extensive simultaneous dental work on neighbouring carious teeth. One individual with recurrent gastrointestinal bloating following routine hyperbaric exposures (sometimes associated with vomiting or explosive diarrhoea after exiting the chamber) retired from in-chamber service when it became apparent that her tendency to air-swallow could not be overcome.

One attendant failed to divulge in her pre-employment medical examination that she had previously been diagnosed with 'benign fasciculation syndrome' after seeking investigation for multiple sclerosis from a neurologist. She reported symptom exacerbation (fatigue and increased fasciculations in her back and arms) lasting up to 24 hours post-dive; symptoms becoming continuous if she dived twice or more per week. A clear temporal relationship was established between symptom deterioration and hyperbaric exposure and, when her background medical condition was clarified, she was stood down from hyperbaric work and declared unfit for recreational diving.

Several workplace medical problems unrelated to hyperbaric exposure occurred.

- A trainee nurse attendant who put her foot through an open access panel in the floor during mopping-up operations following an in-chamber fire drill sustained a soft-tissue neck injury and a spiral fracture of the right fibula.
- A technician whose hand slipped whilst working on a valve/pipeline stabbed himself in the left first web-space with a screwdriver (no neurovascular damage).
- A nurse developed right neck/trapezius pain and tenderness after attending to a patient's dressing in an awkward position (outside chamber, no dives for >48 hours prior to injury).

Table 1
Demographic data for 155 chamber attendants exposed to pressure January 1992 to December 2005

Variable	Female	Male	Combined
Number (%)	108 (70)	47 (30)	155 (100)
Age, yrs Mean (SD)	36.0 (8.5)	35.8 (7.1)	35.9 (8.1)
BMI, kg.m^{-2} Mean (SD)	23.5 (3.1)	26.0 (3.5)	24.4 (3.3)
Exposures during study period			
Range	1–601	1–107	1–601
Mean (SD)	64 (117)	19 (38)	47 (95)
Total	5,153	909	6,062
%	85	15	100

Table 2
Hyperbaric chamber runs 1992 to 2005
msw – metres' sea water depth
† pressure (msw):time at pressure (min): decompression time (min)
‡ binomial 95% confidence intervals for actual zero incidence of DCS

Treatment tables	Number	DCS 95% CI‡
Comex 30	1	
30 msw (misc.)	4	
RN 62 / USN 6	169	0.00, 2.16
RN 61 / USN 5	8	0.00, 36.94
'18:60:30'†	561	0.00, 0.66
18 msw (misc.)	39	
>14<18 msw (misc.)	1	
'14:90:20'†	4,079	0.00, 0.09
'14:60:15'† (obsolete)	815	0.00, 0.45
>10<14 msw (misc.)	81	
10 msw (misc.)	45	
<10 msw (misc.)	18	
Total	5,821	0.00, 0.06

One individual passed his initial pre-employment dive medical but encountered difficulties with recurrent sinus pain during training, with three training dives being aborted. No symptoms or signs other than pain (fully reversed on return to surface) were encountered. He discontinued training as a hyperbaric attendant.

Three instances of pre-existing acute illness (not work-related) were recorded as impacting on chamber operations. One attendant reported for work following a febrile illness the previous night (not disclosed prior to pressurization) and had to be replaced during a patient treatment when she spiked a fever at depth. Another attendant was replaced during a treatment when discomfort from an ocular foreign body acquired on the way to work became intolerable. One episode of non-hyperbaric-related middle-ear barotrauma

Table 3
Work-related hyperbaric personnel injuries from January 1992 to December 2005
URTI – upper respiratory tract infection

Condition	Number	Associated with URTI
Decompression sickness	0	
Gas toxicity incidents	0	
Barotrauma		
Inner ear	0	
Middle ear (15 episodes, 3 bilateral)		
Grade O	9	3
Grade I	5	5
Grade II	4	3
Grade III	0	
Grade IV/V	0	
External ear	1	
Sinus	3	1
Dental/Odontalgia	4	
Gastrointestinal	1	
Worsening of pre-existing neurological condition	1	
Unrelated to hyperbaric exposure	3	
Total	**31 (28 episodes)**	

was noted in a nurse who reported for work with a URTI and remained outside the chamber but was subsequently unable to return home to >500 metres above sea level (hospital at sea level) at the end of the day. Review following her attempt to get home demonstrated bilateral Grade III middle-ear barotrauma. She was obliged to stay with friends at sea level for several days before being physically able to return to her own home.

Four individuals failed their pre-employment dive medicals; one for severe hypertension, two for profound unilateral sensorineural deafness and one for mild bilateral sensorineural deafness combined with difficulty equalizing middle-ear pressures during the attendant training course.

In summary, during a 14-year period, 18,124 patient treatments were performed, requiring 6,062 attendant exposures in a multiplace chamber. No cases of DCS occurred (95% CI 0.00, 0.06%). The incidence of work-related staff health problems was 28 per 6,062 exposures (0.46%), with 25 per 6,062 (0.41%) being pressure-related, the vast majority of which were of a minor or trivial nature. No hyperbaric-specific injuries resulted in formal injury compensation claims, though restorative dental work was paid for in one case of obvious dental barotrauma.

Discussion

Workplace injuries pose a major concern to the healthcare industry. Registered nurses in Australia are reported to have an incidence rate of compensated injuries of 14.34 per million hours worked.[6] Given that it is widely acknowledged that over half of the injuries or illnesses sustained by this group at work are not reported, and only a small proportion of those reported result in compensation, the true incidence of workplace injury is likely to be considerably higher.[6–8] It is against this backdrop that the risks of employment as a multiplace hyperbaric chamber attendant must be measured.

Registered nurses constitute the majority of in-chamber attendant exposures to hyperbaric conditions (98.4% in this series). In its general (i.e., non-hyperbaric) duties this professional group is second only to truck drivers and manual labourers in its incidence of musculoskeletal injuries resulting in lost work days.[9] These injuries primarily involve the back and are generally related to the manual handling of patients. Low back problems are reported to have a point prevalence of 17%, an annual incidence of 40–50% and a lifetime incidence of 35–80% amongst nurses.[10] In our study, this type of injury was not encountered as a result of work within the hyperbaric environment. The traditional concern regarding DCS risk within the hyperbaric community means that personnel maintain a high index of suspicion for musculoskeletal symptoms and are obliged to report any such symptoms arising during their employment with us.

DCS, although potentially serious if it occurs, is an injury the incidence of which can be reduced to acceptable (near-zero) levels by the adoption of suitably conservative decompression strategies and the addition of O_2 breathing. Published data for USN 6 quotes a 6.2% probability of DCS in attendants, rising to 11.1% if the table is extended at 284 kPa, if the attendant breathes air throughout.[11] These rates are halved if the attendant breathes oxygen for the 30-minute decompression to the surface, and diminished to nearly zero if the attendant's O_2-breathing time is extended to coincide with the patient's final 60-minute oxygen period at 182 kPa.

A ten-fold variation in the incidence of DCS in chamber attendants has been reported to date. Dunford reported a 0.31% incidence in 8,424 hyperbaric exposures over 14 years and Dietz a 0.076% incidence in 25,164 exposures over 23 years.[12,13] Both of these authors report a correlation between increasing pressure and DCS incidence. Klossner described a 1.3% DCS incidence over 232 exposures on a 284 kPa table derived from Finnish amateur diving tables.[2] The risk of DCS was reduced to 0.14% over the next 713 exposures by a combination of reducing the treatment pressure to 253 kPa, extending decompression times and adding oxygen breathing by the attendant both during decompression and for 10 minutes at the start of the table.

The highest incidence of DCS reported on a 240 kPa table (100-minute isobaric phase, seven-minute decompression) is 0.76%. Those authors attempted to reduce this incidence by modification of their attendants' breathing gases.[1,3] Unfortunately they were unable to establish a procedure that met institutional acceptance criteria.[3] Using DCIEM tables, their profile would have required a five-minute decompression stop at 3 msw gauge pressure and their routine seven-minute linear decompression from 240 kPa may not have been adequate to compensate for this. The University Hospital to which they were affiliated subsequently discontinued elective hyperbaric treatments in the multiplace chamber to eliminate the inherent risk to their staff. This contrasts strongly with the zero incidence of clinical DCS in our study. Had these reported DCS incidence rates held true for our table, 46–60 cases of clinical DCS would have occurred during our first 14 years of operation and the three most prolific regular attendants (with between 369 and 601 dives each) could have expected to be 'bent' three to six times each. This was fortunately not the case.

With no DCS amongst our chamber attendants, our focus turned to other staff health concerns. Minor ENT barotrauma was the most common hyperbaric-specific injury evident in this study. If injuries unrelated to pressurization (e.g., incurred during patient dressings, equipment maintenance and cleaning) are discounted, what proportion of the remaining hyperbaric-specific injuries was potentially preventable? Grade 0 middle-ear barotrauma (symptoms but no signs) may be legitimately thought of as a warning of impending harm rather than an injury per se. If Grade 0 middle-ear barotrauma, together with the situation where an individual deliberately withheld pertinent medical information at the time of employment (a pre-existing neurological condition), were excluded, we were left with 18 barotraumatic injuries (1 per 337 exposures) – half of which occurred in conjunction with a recent URTI. Existing unit guidelines require attendants not to dive following URTI until free movement of their tympanic membranes is verified by the duty doctor. More rigorous enforcement of these guidelines may therefore reduce this problem. Likewise the incidence of odontalgia or dental barotrauma may be amenable to modification by insisting on regular dental review for all personnel.

This leaves a 0.08% incidence (5 per 6,062) of potentially non-preventable hyperbaric-specific events: one episode of unilateral Grade II middle-ear barotrauma (in an experienced attendant); two episodes of sinus pain, not associated with obvious recent URTI; one episode of external ear barotrauma associated with unsuspected cerumen plugging; and one idiosyncratic case of gastrointestinal bloating due to air swallowing, not amenable to remediation. A multiplace hyperbaric chamber can, therefore, be viewed as a potentially safe working environment, especially when compared to the known incidence of back injury associated with general ward nursing duties.

Although the respective merits and disadvantages of multiplace versus monoplace facilities have caused considerable debate – with strong proponents for both views – it is our opinion that there will always be some patients for whom the immediate, hands-on attendance of a trained nurse (+/- a physician) will be mandatory. If these patients are not to be disadvantaged by either being denied access to HBOT or subject to it under conditions which separate them from immediate direct contact with the staff caring for them, then multiplace chambers (and the associated exposure of attendants to pressure) will remain a necessary part of hyperbaric medicine. Likewise, if multiplace chambers remain in service at any level, it would seem obligatory to ensure that personnel exposed to this environment are sufficiently comfortable and proficient at functioning in-chamber that there is no reduction in the response time to potential crises. We believe that regular exposure to this environment during routine treatments plays an essential role in the maintenance of a safe workplace.

Conclusion

This 14-year review of multiplace hyperbaric attendant health demonstrates that maintenance of a safe workplace for in-chamber attendants does not pose a serious problem. Conservative decompression strategies on our most frequently used (institution-specific) 243 kPa table and routine use of oxygen are likely to account for our low DCS risk when compared with previously published series. Minor degrees of ENT barotrauma were the most commonly encountered hyperbaric-specific injury. Overall injury rates compare favourably with those encountered by the nursing profession in other areas of practice. Our institutional policies and procedures appear to provide an acceptably safe working environment and therefore, will remain unchanged.

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Paul David Cooper, MB, ChB, FJFICM, FANZCA, DipDHM, was initially Senior Registrar in Hyperbaric & Diving Medicine, then subsequently Deputy Director of Anaesthesia and Staff Specialist in Intensive Care and Diving & Hyperbaric Medicine, Royal Hobart Hospital, Hobart, Australia during the study period.
Corry Van den Broek, DipAppSc, CPO-CD (RANR), is the Facility Manager and Senior Hyperbaric Technical Officer, Department of Diving & Hyperbaric Medicine, Royal Hobart Hospital, Hobart.
David Smart, MBBS (Hons), MD, FACEM, FIFEM, FACTM, FAICD, DipDHM, is Medical Co-Director, Department of Diving & Hyperbaric Medicine, Royal Hobart Hospital, and Director of Emergency Medicine, Calvary Health Care, Hobart.

Address for correspondence:
Dr David Cooper,
Department of Diving & Hyperbaric Medicine,
Royal Hobart Hospital,
GPO Box 1061L, Hobart,
Tasmania 7001, Australia
Phone: *+61-(0)3-6222-8193*
Fax: *+61-(0)3-6222-7268*
E-mail: *<david.cooper@dhhs.tas.gov.au>*

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