Oxygen toxicity seizures: 20 years' experience from a single hyperbaric unit

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Abstract

(Banham NDG. Oxygen toxicity seizures: 20 years' experience from a single hyperbaric unit. *Diving Hyperb Med.* 2011 December;41(4):202-210.)

Introduction: Oxygen toxicity seizures (OTS) are a known complication of hyperbaric oxygen therapy (HBOT). The incidence of OTS has been variously reported and appears to be related to the duration and pressure of exposure in addition to individual susceptibility factors.

Method: All OTS occurring in patients undergoing HBOT during the first 20 years of operation of the Fremantle Hospital Hyperbaric Medicine Unit were reviewed.

Results: During 41,273 HBOT exposures in 3,737 patients, 25 OTS occurred; a rate of 0.06% (1/1,651 or 6 per 10,000 HBOT exposures). For the initial treatment of dysbarism with United States Navy Treatment Table 6, the rate was 0.56% (4/714) and for the treatment of carbon monoxide (CO) poisoning it was 0.18% overall but 0.49% for the first HBOT. There was an increasing OTS rate with increasing pressure with a statistically significant difference ($P < 0.001$) in OTS rate at 203 kPa or less versus > 203 kPa (odds ratio (OR) 8.5, 95% confidence intervals (CI) 2.0 to 36.1), and for comparison of two commonly used pressures of 203 kPa versus 243 kPa ($P = 0.028$, OR 5.1, 95% CI 1.1 to 22.8), but not with first versus follow-up HBOT at 284 kPa for dysbarism ($P = 0.061$) nor CO poisoning ($P = 0.142$).

Conclusions: This study reports all OTS in a single hyperbaric unit over a 20-year period; the longest observational study period yet reported for OTS during HBOT for all indications. The incidence of OTS in this study compares favourably to previously reported rates, and shows an increasing OTS rate with increasing pressure.

Key words

Central nervous system, oxygen, toxicity, seizures, hyperbaric oxygen, hyperbaric oxygen therapy

Introduction

Oxygen toxicity seizures (OTS) are a well recognised but uncommon complication of exposure to oxygen at pressures greater than 1 atmosphere (101.3 kPa, hyperbaric oxygen). OTS (in animals) was first described by Paul Bert in 1878; CNS oxygen toxicity is now known as the Paul Bert effect.[1] OTS occurring in humans was first observed by Damant and Phillips in 1933, who breathed 100% oxygen in compressed air at 405 kPa and had convulsive symptoms at 16 and 13 minutes respectively.[2] Experiments by Donald during World War II resulted in oxygen toxicity seizures in experimental divers – at that time "*no experimental dives where men had breathed pure oxygen at toxic tensions under water had yet been reported*".[2] Donald's experiments found a large variation in oxygen tolerance in his group of human subjects, as well as an "*individual variation, which is found to be over an enormous range*".[2]

A review of OTS was recently published by Bitterman, briefly presenting the features, dosing, risk factors, mechanisms of and protection against hyperoxic seizures.[3] Risk factors included 'wet' diving compared to 'dry' chamber diving, elevated concentrations of carbon dioxide and exercise. The mechanism of OTS, however, remains poorly understood. The rate of OTS in patients undergoing hyperbaric oxygen therapy (HBOT) has been variously reported and seems dependent on the exposure table (time and pressure), the condition treated and perhaps even the method of oxygen delivery (face mask versus head hood versus monoplace chamber).[4-15] *

The aim of this study was to determine the rate of OTS in all patients treated with HBOT during the first 20 years of operation of the Fremantle Hospital Hyperbaric Medicine Unit (HMU). The HMU provides a 24/7 365 days a year emergency service covering all of Western Australia as well as providing an elective hyperbaric service predominantly for the metropolitan areas of Perth and Fremantle. We also wished to examine OTS rates for different treatment pressures, indications and chamber types. A synopsis of the peer-reviewed published literature appears in Table 1.

Methods

Written approval for data extraction and review was obtained from the Human Research Ethics Committee of the South Metropolitan Area Health Service, Perth, Western Australia. A prospective database of all OTS has been maintained in the HMU since the opening of the unit in November 1989. A manual (book) database including OTS patient clinical details, treatment profile and OTS description was checked

*** Editor's footnote:**
Many of the reports of OTS are in abstract form only. As per this Journal's policy, these are not included in Table 1 or the references list since there are sufficient data published in the peer-reviewed literature. A full list is available on request from the author.

Table 1
Oxygen seizures during HBOT as reported in previous peer-reviewed publications (O_2 – oxygen; DCI – decompression illness; CO – carbon monoxide; CAGE – cerebral arterial gas embolism; USN TT6 – United States Navy Treatment Table 6)

Author	Treatment pressure (kPa)	Location	Chamber type	Method of O_2 delivery	Patient type	Incidence
Sanders et al[4] 2009	243 + 284	Single unit	Monoplace	Not stated	All	0.03%, 2/5,972 = 1/2,986 CO: 2/171 (1.17%)
Weaver[5] 2006	284	Single unit	Monoplace	O_2-filled monoplace; 7 ventilated	Divers + CAGE	1.11% 1/90
Smerz[6] 2004	PO_2 263–294 Hawaiian Tables	Single unit	Multiplace	Not stated	Divers	0.65%, 14/2,166 = 1/155
Wilkinson et al[7] 2005	284	Single unit	Multiplace	Not stated	Divers/CO/ wounds/other	0.28%, 17/6,084 = 1/358
Yildiz et al[8] 2004	203–284	2 units	Monoplace + Multiplace	Mask usually	Routine HBOT	0.002%, 2/80,679 = 1/40,339
Yildiz et al[9] 2004	239–284	Single unit	Multiplace	Mask usually	Routine and emergency	0.008%, 3/36,500 = 1/12,166
Hampson & Atik[10] 2003	239	Single unit	Multiplace	Head hoods	Routine HBOT	0.03%, 6/20,328 = 1/3,388
Plafki et al[11] 2000	243–253	2 units	Multiplace	Masks or hoods	All (? not CO)	0.04%, 4/11,376 = 1/2,844
Hampson et al[12] 1996	248/284/304 (300 at each)	2 units	Multiplace	? Head hoods but 15% ventilated	CO poisoning	1.8%, 16/900 = 1/56 0.3% at 248 kPa 3.0% at 284 kPa 2.0% at 304 kPa
Weslau & Almeling[13] 1996	243–304	19 units via survey	18 Multiplace 1 Monoplace	Not stated	Routine + divers	0.015%, 16/107,264 = 1/6,704
Sloan et al[14] 1989	304	Single unit	Multiplace	Mask; 18% ventilated	CO poisoning	4.71%, 14/297 = 1/21
Davis[15] 1989	243	2 units	Multiplace	Hoods	All	0.01%, 5/52,758 = 1/10,552
Banham 2011	193–405	Single unit	Multiplace + Monoplace (from 2001)	Hoods in multiplace	All	0.06%, 25/41,273 = 1/1,651

Notes:
1. Published pressures in Ata or depths of seawater equivalent have been converted to kilopascals (kPa).
2. Percentages rounded to two decimal places where possible.

with our electronic database from 27 November 1989 to 26 November 2009, a period of exactly 20 years. Further details of each OTS were cross-checked with the treating physicians' and chamber attendants' documentation in the patients' medical records and also with the HMU technicians' dive logs that are recorded for every chamber compression. Records from each OTS patient pertinent to this study were copied and collated for manual data extraction. No patient identifying information was recorded. Statistical analysis of data was via Fisher's Exact Test. Statistical significance was assumed where $P < 0.05$.

Results

The presence of prodromal symptoms was documented in 10 out of 25 cases of OTS. Prodromal features included twitching, staring gaze, auditory hallucinations, anxiety and irritability. Despite cessation of oxygen (O_2) with prodrome, these cases still proceeded to a convulsion almost immediately. The remaining 15 cases had a convulsion as their first overt evidence of cerebral O_2 toxicity. In total, 25 OTS in 21 patients occurred in 41,273 HBOT exposures (3,737 patients), a rate of 1/1,651 (0.06%) or 6 per 10,000 HBO sessions. Details of the individual cases are shown in Table 2. All of the OTS were generalised in nature. Episodes of OTS prodrome that did not progress to a seizure were not included in this study. The OTS rate per chamber type and treatment pressure, including initial treatment of dysbarism is shown in Table 3.

A further seizure that occurred in this 20-year period was almost certainly a hypoglycaemic event as the blood glucose at the time of seizure was 1.4 mmol L^{-1}. This patient was an insulin-dependent diabetic who had very labile blood sugars during HBOT with frequent drops requiring intervention. This case as such, was excluded from OTS rate

Table 2
Details for 25 oxygen toxicity seizures (OTS) in 21 patients over a 20-year period at (DCI – decompression illness; CO – carbon monoxide; CAGE – cerebral arterial gas embolism; ORN – osteoradionecrosis; STRN – soft-tissue radiation necrosis;

Case	Age	Sex	Indication for HBOT	kPa of OTS	Chamber type	HBOT No.	Total HBOT
1	22	M	Crush injury	284	Multi	1	6
2	58	M	Venous ulcers	284	Multi	3	20
3	28	M	CO poisoning	284	Multi	1	2
4	20	F	CO poisoning	284	Multi	1	3
5	31	M	CAGE (diver)	193	Multi	1	11
6	27	M	Gas gangrene	284	Multi	1	2
7	24	M	CAGE (diver)	284	Multi	1	2
8	36	F	DCI	284	Multi	1	2
9	36	F	DCI	284	Multi	1	2
10	28	F	Crush injury	203	Multi	1	1
11	23	M	Crush injury	284	Multi	2	3
12	68	F	Ischaemic foot	243	Multi	1	1
13	22	M	Compartment syndrome	284	Multi	1	3
14	67	M	Venous ulcers	243	Multi	12	13
15	58	M	ORN prophylaxis	243	Multi	26	27
16	14	M	Crush injury	243	Mono	1	8
17	65	M	ORN prophylaxis	203	Mono	27	27
18	81	F	Non-healing wound	193 (243 kPa table)	Multi	22	28
19	57	M	ORN	243	Multi	15	40
20	52	F	ORN	243	Multi	6	9
21	57	M	ORN prophylaxis	243	Multi	28	30
22	78	F	Diabetic ulcer	243	Multi	11	37
23	78	F	Diabetic ulcer	243	Multi	15	37
24	74	M	STRN	243	Multi	13	30
25	78	F	Diabetic ulcer	193 (243 kPa table)	Multi	37	37

Table 2 (cont.)
Fremantle Hyperbaric Medicine Unit; three patients had more than one OTS; see text for details of treatment tables used USN TT6 – United States Navy Treatment Table 6; EEG – electro-encephalogram; CT – computerised tomography; MRI – magnetic resonance imaging; "End of" implies OTS occurred close to end of an O_2 period)

O_2 Period	Time on O_2 (min)	BSL (mmol L^{-1})	Risk factors	Comments
End of 2nd	48	-	?Nil	Pethidine 75 mg several h prior
End of 2nd	48	-	Nil	Usually at 203 kPa; this HBOT at 284 kPa to fit with other patients; same patient as 14
End of 1st	23	-	Nil	—
End of 2nd	48	-	Nil	—
Start of 4th	125	-	Salt water aspiration	P_aCO_2 48 mmHg several h prior; USN TT6
End of 2nd	48	-	Nil	Afebrile at the time
End of 3rd	59	-	Nil	USN TT6
End of 1st	16	-	Nil	USN TT6; EEG post-HBOT epileptiform; CT brain normal; same patient as 9
End of 3rd	55	-	Nil	USN TT6; same patient as 8
1st	17	-	approx. 1,300 mg pethidine in 30 h	HBOT aborted
End of 1st	24	-	Nil	—
2nd	68	-	Acetazolamide; pethidine	HBOT aborted
End of 1st	25	-	Morphine IV pre-HBOT	Drowsy
End of 2nd	77	-	Prior OTS	Same patient as 2
End of 2nd	84	-	Nil	—
End of 2nd	77	-	?Nil	Flucloxacillin 1g 6 hourly IV
12 mins prior to decompression	108	4.8	Nil	Final post-op HBOT not given
5 mins into 10 min stop at 193 kPa	90	8.1	Prednisolone 10 mg daily; amitriptylline 10 mg nocte	—
1st	34	4.2	Alcohol abuse	—
1st	32	7.4	Nil	Pre-syncope during 9th HBOT; HBOT ceased; EEG + MRI brain normal
End of 2nd	85	-	Nil	Diazepam 10mg pre-HBOT for claustrophobia
End of 2nd	87	4.9	Insulin	Same patient as 23 and 25; morbid obesity
End of 1st	40	6.7	Insulin; prior OTS	Same patient as 22 and 25
End of 1st	44	5.2	Nil	—
On decompression	90	8.6	Insulin; prior OTS	Same patient as 22 and 23

Table 3
Oxygen toxicity seizures (OTS) rate per chamber type and treatment pressure including initial treatment of dysbarism; an OTS that occurred during decompression in a table is included in the data for that table (USN TT6 – United States Navy Treatment Table 6)

Treatment table/pressure (kPa)	HBOT sessions	OTS number	OTS %	OTS rate
Multiplace chamber	36,068	23	0.06	1/1,568
COMEX 30	7	0	0	0
USN TT6	593	4	0.67	1/148
203	15,732	1	0.01	1/15,732
243	17,847	11	0.06	1/1,622
284	1,889	7	0.37	1/270
Monoplace chamber	5,205	2	0.04	1/2,602
USN TT6	121	0	0	0
193	36	0	0	0
203	1,780	1	0.06	1/1,780
243	2,786	1	0.04	1/2,786
284	482	0	0	0
Totals for treatment type				
COMEX 30	7	0	0	0
USN TT6	714	4	0.56	1/178
193	36	0	0	0
203	17,512	2	0.01	1/8,756
243	20,633	12	0.06	1/1,719
284	2,371	7	0.30	1/339
TOTAL	41,273	25	0.06	1/1,651

analysis, although it is possible that the seizure was due to a combination of hypoglycaemia and hyperoxia.

PRESSURE

The rate of OTS at 203 kPa or less (2 /17,548) versus OTS occurring at all treatment pressures greater than 203 kPa (23/23,725) shows a significant difference in OTS rate between the two treatment pressures ($P < 0.001$, odds ratio (OR) 8.5, 95% confidence intervals (CI) 2.0 to 36.1). Comparison of the OTS rate at 203 kPa versus 243 kPa shows a significantly lower rate at 203 kPa ($P = 0.028$, OR 5.1, 95% CI 1.1 to 22.8). Exclusion of those with their first HBOT for dysbarism (4/721) from the above data still shows statistical significance with 2/17,548 versus 19/23,004 ($P = 0.001$, OR 7.3, 95% CI 1.7 to 31.1).

MULTIPLACE VERSUS MONOPLACE CHAMBER

Overall, 36,068 of 41,273 cases were treated in a multiplace chamber; these cases comprised 23 of the 25 OTS that occurred (difference not significant, $P = 0.762$).

OTS TIMING

The most frequent timing for OTS (9/25 cases) was in the final third of the second O_2 period, followed by OTS occurring at the end of the first O_2 period (6/25 cases). In divers being treated for dysbarism, four OTS occurred after the second O_2 period (one during the third O_2 period, one during a table extension in their fourth 20-minute O_2 period at 284 kPa and two at 193 kPa during the decompression phase of HBOT). There were three cases that occurred in the first two thirds of the first O_2 period and one in the same period of the second O_2 period. The other OTS in our series was in the monoplace chamber at 203 kPa, occurring near the end of this table. The accrued time on oxygen to the time of the OTS (excluding air breaks) is listed in Table 2. Analysis of these times shows a mean of 58 min, a mode and median of 48 min and a range of 16 to 125 min.

CO POISONING

There were 1,088 HBOT for acute CO poisoning, 409 first treatments and 679 follow-up HBOT, all at 284 kPa. Two OTS occurred during a first treatment, 0.49%. The overall OTS rate was 0.18%. The different between first and subsequent HBOT was not statistically significant ($P = 0.142$, 95% CI 0.09 to 1.95).

DYSBARISM

Dysbaric injuries comprised decompression illness (DCI) in divers and iatrogenic cerebral arterial gas embolism (CAGE). The OTS rate for the initial treatment of dysbarism (4/721) with either USN TT6 or COMEX 30 (Compagnie Maritime

d'Expertises) table was not different to that for follow up with United States Navy Treatment Table 5 (USN TT5) (0/731) (P = 0.061). The profile for the first two oxygen periods in a USN TT5 is identical to that of a USN TT6.

RECURRENT OTS

Three of the 21 OTS patients had a recurrent OTS, with one of these having a third convulsion. The first patient (listed as events 2 and 14 in Table 2) was receiving HBOT for non-healing venous leg ulcers. His first OTS occurred in the third of a course of 20 HBOT in 1992, without prodrome. His recurrent seizure was in 2001 at 243 kPa during his twelfth HBOT session for recurrence of non-healing venous leg ulceration. This OTS was immediately preceded by facial grimacing. His next treatment was modified to reduce the likelihood of recurrent OTS by increasing the duration of the air break from 5 to 10 minutes, but the patient became extremely anxious about the possibility of a further OTS and declined further HBOT.

The second patient (8 and 9 in Table 2) was a 36-year-old, experienced female scuba diver who had onset of constitutional and musculoskeletal symptoms suggestive of DCI. She was treated with a USN TT6 in the multiplace chamber. An OTS occurred near the end of the first 20-minute O_2 period and again towards the end of the third, despite the administration of diazepam 4 mg IV during the first OTS. Further diazepam was administered and the table completed without incident. Both OTS were preceded by a brief prodrome (anxiety and auditory hallucinations) and occurred despite immediate O_2 delivery cessation. The patient had a 203 kPa HBO treatment the next day without incident. In view of these seizures, she was investigated for an underlying seizure disorder. A computerised tomography scan of her brain was normal but an electroencephalogram (EEG) performed 12 days post seizure was reported as showing findings typical of generalised epilepsy. However, a repeat EEG eight years later was normal. Recent contact with the patient revealed that she had had no further seizures, had resumed diving and had also been recompressed again on a USN TT6 in 2005 without incident.

The third patient (22, 23 and 25 in Table 2) with recurrent OTS was an obese Type-2 insulin-dependent diabetic with a chronic non-healing leg ulcer having HBOT at 243 kPa. Her three OTS all occurred without prodrome and with a normal BSL. Following the second, the decision as to whether to continue with HBOT was discussed with the patient, and as she was very keen to continue, it was decided to give an extra 5-minute air break in the middle of each of the two scheduled 45-minute oxygen periods at 243 kPa. Despite this, the patient had a further OTS at 193 kPa (on decompression from 243 kPa) during HBOT session number 37, and HBOT was discontinued. No further investigation of her seizures was undertaken. Of the 18 patients with a single episode of OTS, all but two had further HBOT ranging from 1 to 25 sessions.

OTS TREATMENT

Pharmacological treatment with benzodiazepines was given in eight cases, and a further patient who was an insulin-dependent diabetic was given glucagon empirically pending the result of a finger-prick blood glucose, which was within the normal range.

Discussion

OTS PRODROME

Prodromal symptoms of OTS were described in detail by Donald and included lip twitching, visual changes, nausea, vertigo, auditory hallucinations and spasmodic breathing.[2] Damant and Phillips in 1933 in their self-experimentation breathing O_2 at 405 kPa both had tremor of the lips, which resolved in one by immediately reverting to air breathing; the other, however, progressing to convulsions and unconsciousness despite reverting to air breathing.[16] Less than half (10/25) of OTS patients in this series were noted to have warning signs of an impending OTS. Prodromal features included twitching, vacant or staring look, anxiety, auditory hallucinations and nausea. Despite immediate cessation of O_2 upon recognition of an impending OTS, there was a rapid progression to a seizure. However, the majority of patients in this series had an OTS as their first manifestation of cerebral O_2 toxicity.

OTS TREATMENT PRESSURE

The rate of OTS at 203 kPa or less (2/17,548) was statistically significantly less than that at treatment pressures greater than 203 kPa (23/23,725). This is consistent with many reports, dating back to the time of Donald, showing an increased OTS rate with increasing pressure.[2] Seizures occurred at all treatment pressures, the lowest being 193 kPa; but only during depressurisation from a higher treatment pressure, (203, 243 and 284 kPa). The only exception was during the COMEX 30 table, used only seven times during this period. That no OTS occurred with COMEX 30 treatments is likely due to the small number of patients treated with this table in this series. At 405 kPa and until depressurisation to 284 kPa, patients breathe 50:50 Heliox, with an FiO_2 of only 203 kPa. The rest of the COMEX table is, however, completed with periods of 100% O_2 breathed at 284 then 223 kPa.

Almost all OTS in this series occurred at a treatment pressure of 243 kPa or more. There were only two cases of OTS during a 203 kPa table; one in the multiplace chamber and one in the monoplace. The OTS in the multiplace at 203 kPa occurred in a 28-year-old female who sustained a crush injury to her right hand for which she had received 1,300 mg of pethidine analgesia over the 30 h prior to HBOT. Pethidine's metabolite norpethidine is recognised

to cause seizures.[17] Norpethidine may have potentiated the CNS toxicity of O_2 in this patient, leading to the OTS early in the first O_2 period at a pressure at which OTS is cited to be uncommon.[18]

The patient with OTS in the monoplace chamber at 203 kPa was a 65-year-old man with previous radiotherapy post-laryngectomy, being treated with HBOT as prophylaxis to prevent mandibular osteoradionecrosis (ORN) post dental extraction. The treatment table was 10:120:06 (10 metres' sea water (msw) depth equivalent [203 kPa], 120 min of O_2 with no air break and 6 minute decompression). He had had 26 prior similar HBOT sessions without problems. At 108 min into the treatment, he had a grand-mal type seizure lasting approximately 3 min. No specific therapy was given aside from ceasing the O_2 supply to the monoplace chamber and immediately flushing it with air. There were no apparent predisposing factors to OTS and his finger-prick blood glucose was normal (4.8 mmol L^{-1}) upon surfacing the chamber. As his dental clearance wounds were now well healed, it was decided to stop his HBOT at this point.

Twelve OTS occurred during treatments at 243 kPa in 10 patients. HBOT administered at 243 kPa has been the routine treatment compression pressure in Fremantle Hospital HMU since February 1999; the change from 203 kPa to 243 kPa was to comply with the Marx and Wilford-Hall treatment protocols.[19,20] Of the 12 OTS at 243 kPa, only two occurred with the first HBOT. One patient (Case 12) had been medicated with acetazolamide and pethidine, both recognised as potential precipitating factors for OTS.[17,21] The other OTS occurring at 243 kPa during a first treatment was in a 14-year-old male with a crush injury to his right ankle (Case 16), being treated in the monoplace chamber on a 14:90:08 table (two 45-minute periods on oxygen with a 5-min air break via mask at 243 kPa and 8 min decompression). The OTS occurred at 77 min on oxygen. The chamber was flushed with air, the patient breathed air for 15 min then resumed oxygen for decompression. He had a further 14:90:08 HBO treatment the next day, then six 10:120:06 treatments, all without incident.

OTS TIMING

It has been suggested that the majority of seizures occur in the final third of the second O_2 period. In the present series, this was also the case (9/25 cases), followed by OTS occurring at the end of the first O_2 period (6/25 cases). The variation in timing of OTS both regarding the timing during a treatment and the HBOT session in which it occurred are again consistent with the observations of Donald who reported a wide variation in susceptibility between subjects as well as an enormous individual variation.[2] As such, there should be a heightened awareness of the increased likelihood of an OTS in the approach to an air break, with the understanding, however, that an OTS may occur earlier in the period of O_2 breathing.

METHOD OF O_2 DELIVERY

We did not observe a difference in OTS rate between multiplace and monoplace treatments. Almost all patients in this series had O_2 delivered via a head hood when compressed in a multiplace chamber, apart from a few, usually divers, who preferred using a mask. Mask delivery of O_2 was also used for patients in the monoplace chamber when at pressures greater than 243 kPa. The design of head hood used over the 20 years has remained constant, with the inflow and outflow tubing ports adjacent to each other at the front. Monoplace HBOT at 284 kPa has O_2 delivered via mask in an air-filled chamber, whereas at 243 kPa or less, the monoplace is compressed with 100% O_2 and air breaks are via mask. It was not possible to compare OTS rates between these various modalities of oxygen delivery in our series. OTS is a relatively rare event and hence extremely large numbers of patients and treatments would be required to show whether any one modality of treatment (mask, hood, monoplace and multiplace) was safer than any other. Also, most higher pressure and longer duration tables, such as USN TT6 and COMEX 30 treatments occurred in the multiplace chamber.

RECURRENT OTS

Only three of 21 patients had a recurrent OTS. Of these, one had a recurrence in the same HBOT session, one during the same course of HBOT (3 OTS in total) and one in two HBOT courses nine years apart. Continuation of HBOT occurred in 16 without further OTS, indicating that ongoing HBOT post OTS is not necessarily contraindicated. Patients who do have recurrent OTS should have a risk assessment as to the need for continuation of HBOT, a review of any factors, especially medications that may predispose them to OTS and consideration of modification to their treatment table to reduce their OTS risk. This could include increasing the frequency of air breaks, or reducing the treatment pressure or both. The use of benzodiazepines or other anticonvulsants may be considered; however, diazepam 4 mg IV did not prevent a recurrent OTS in the diver discussed above.

OTS TREATMENT

Eight of 11 patients with OTS prior to the year 2000 were treated with intravenous benzodiazepines (diazepam or midazolam) in addition to oxygen cessation. One patient (Case 5) required multiple doses of IV benzodiazepines to control post-seizure agitation. From the year 2000, our Unit's OTS protocol was amended such that benzodiazepines were not given routinely in response to OTS, but only for prolonged seizures or post seizure agitation, being required in none of these 12 patients.

With the recognition that HBOT may cause hypoglycaemia in patients with diabetes, whether insulin-dependent or non-insulin-dependent,[22,23] it became routine in our HMU

from 2003 to document a finger-prick blood glucose in such patients immediately before and after each HBOT session and if any hypoglycaemic symptoms or OTS occurred during HBOT. Only one patient with a seizure in the chamber had evidence of hypoglycaemia, and, as such, the remainder of OTS were attributed to and treated as hyperoxic seizures.

CO POISONING OTS

Both OTS in CO-poisoned patients occurred during their first HBOT. This is consistent with a recent review of the data by Sanders et al. who reported that 100% (18/18) of OTS occurred during the first HBOT for CO toxicity compared to 2/8 OTS (25%) during the first HBOT for non-CO related conditions.[4] Sanders et al. commented that they were unable to "*determine whether HBOT increases the risk of seizure in CO-poisoned patients or whether the risk of seizures is simply the result of the CO poisoning*".[4] The rate of OTS in CO patients has been reported variously from 0% to 4.7%.[24] Our series rate of 0.18% OTS (but 0.49% of first HBOT) compares favourably to the average in the reviewed medical literature: 1.45% (32 OTS/2,200 HBOT) for CO-poisoned patients versus 0.008% (8 OTS/106,158 treatments) for HBOT for indications other than CO poisoning. It is also very similar to the 0.2% reported by Wilkinson (which is not included in Sanders' analysis).[4,7] There was no significant difference in the OTS rate for the first versus follow-up HBOT for CO poisoning.

DYSBARISM OTS

Our overall rate of 0.28% for dysbarism treated at 284 kPa compares favourably to the range of 0.49% to 1.11% reported by others.[5–7] The rate of OTS for patients for their initial treatment for dysbarism in this series (4/721, 0.56%) was less than that reported by another Australian hyperbaric unit of 1.64% (7/427).[7] Of these, four occurred during USN TT6 and the other three during an 18:60:30 table. Both of these treatment tables have identical initial three 20-minute O_2 periods. This difference in OTS rates between the two hyperbaric units in the same country treating similar diving populations is unexplained. Interestingly, there were no cases of OTS in any of the iatrogenic or diving-related CAGE reported by the Adelaide unit. There were no cases of OTS documented in the 1,632 HBOT for dysbarism following their first compression despite the fact that the profile for the first two O_2 periods of a USN TT5 is identical to that of the USN TT6. This may be explained simply by the relatively low number of patients in this cohort.

The higher rates of OTS for the initial treatment of dysbarism and CO poisoned patients at 284 kPa compared to elective treatments at 243 kPa warrant that appropriate information regarding this is provided to such patients during the process of gaining informed consent for their HBOT. In addition, attendants and technicians should have a heightened awareness of the risk of OTS and the recognition of any prodromal O_2 toxicity symptoms with consequent cessation of O_2 in an attempt to avoid OTS in this group of patients.

ASSOCIATED RISK FACTORS

No patient with an OTS had a documented past history of seizures or a fever (temperature > 37.5°C) during the HBOT session where the OTS occurred.

Conclusions

This study is the longest longitudinal study yet published of all OTS occurring in all patients for all treatment indications in a single hyperbaric unit.

It demonstrates similar rates of OTS for HBOT administered in Fremantle Hospital's Hyperbaric Medicine Unit to those described elsewhere.

The rate of OTS occurring at a treatment pressure of ≤ 203 kPa is significantly less than for pressures > 203 kPa.

The OTS rate at 243 kPa, our most common treatment pressure, was 12/20633 (0.06%) or 1 in 1,719 treatments.

The OTS rates for the treatment of dysbarism and CO are much higher than for routine HBOT and, as such, appropriate vigilance should be maintained and the relative risk explained to patients or their close relatives prior to compression for these indications.

Prodromal symptoms of cerebral O_2 toxicity are not witnessed prior to the onset of an OTS in a majority of patients.

Acknowledgements

The author would like to thank Sue Thurston, Russell Cronin, Beth Karlsson, Alison Solomon, Owen Phillips and other members of the Fremantle Hospital hyperbaric team for assistance with data extraction and Dr Glenn Arendts for statistical assistance.

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Submitted: 20 April 2011
Accepted: 14 September 2011

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This paper is based on Dr Banham's dissertation submitted towards the SPUMS Diploma in Diving and Hyperbaric Medicine, awarded in 2010.