Pediatric hyperbaric oxygen therapy in Victoria, 1998–2010

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Objectives: The aim of this review is to identify clinical conditions currently treated in a pediatric population referred to the Alfred hyperbaric unit, to describe outcomes, and detail any complications occurring during treatment or transfer between units.

Design: Retrospective, noncontrolled, clinical study.

Setting: Adult hyperbaric unit in a university hospital.


Interventions: Hyperbaric oxygen therapy at pressures from 2.0 to 3.0 atmospheres absolute.

Measurements and Main Results: Fifty-four patients with a median age at presentation of 15 yrs (range, 0.25–16 yrs) received 668 treatment sessions (mean, 12.4; 95% confidence interval, 9.2–15.5). Fourteen patients were identified as having successfully completed treatment while managed in intensive care units. There were 44 events in 668 treatments (6.6%) in the pediatric group and 12 events in 126 treatments (9.6%) in the pediatric intensive care unit group. There were two oxygen toxicity complications (0.3%), two episodes of progressive hypoxemia (0.3%), and four episodes of brief hypotension (0.6%).

Conclusions: Provision of hyperbaric oxygen to children with significant illness is feasible and associated with a low risk of complications. The most difficult aspect of managing pediatric hyperbaric oxygen therapy is in the coordination of the treatment with ongoing surgical and intensive care management. The lack of pediatric staff and facilities in major hyperbaric units necessitates multiple transfers for appropriate treatment. (Pediatr Crit Care Med 2011; 0:000–000)

Key Words: child; complications; hyperbaric oxygenation; infant; intensive care units, pediatric; treatment outcomes

Hyperbaric oxygen therapy (HBOT) is the primary medical treatment for decompression sickness and arterial gas embolism. It is considered an adjunct treatment for necrotizing soft tissue infections, clostridial myonecrosis (gas gangrene), necrotizing fasciitis, acute traumatic ischemias, chronic diabetic and nondiabetic hypoxic problem wounds, chronic refractory osteomyelitis, radiation tissue damage, compromised skin grafts, and some types of intracranial abscesses. The Undersea and Hyperbaric Medical Society (1) defines HBOT as: “A treatment in which a patient breathes 100% oxygen while inside a treatment chamber at a pressure greater than sea level pressure (i.e., >1 atmosphere absolute or ATA).” Hyperbaric chambers are typically operated at pressures >2 ATA for periods of 60–120 mins per treatment session. Such doses of oxygen have a number of beneficial biochemical, cellular, and physiological effects.

Pediatric patients, however, are treated infrequently at hyperbaric units in Australia. A perception of many hyperbaric units is that treatment of children who are critically ill is extremely difficult. Issues raised include the need for transfer of critically ill infants on a daily basis from pediatric units not connected to the hyperbaric unit, lack of adequately trained pediatric consultants with hyperbaric experience, and late or inappropriate referral of children to hyperbaric units. There are also few published series to guide pediatricians, neonatologists, and pediatric intensivists in balancing the risks of transferring a critically ill child with the benefits of HBOT. In addition, a number of misconceptions exist concerning the risks of hyperbaric oxygen, which limit the initial referral of children for treatment (2).

Aim

The primary aim of this review was to identify clinical conditions treated in a pediatric population referred to the Alfred hyperbaric unit. Secondary aims were to describe outcomes of treatment and detail any complications occurring during treatment or during transfer between units.

Setting

The Alfred hyperbaric unit is the major hyperbaric center in Victoria serving a population of 5.43 million. The Alfred Hospital has no pediatric staff and no pediatric inpatient beds so treatment of children required multiple transfers. Critically ill children were transferred by a specialized pediatric emergency transport service from the Royal Children’s Hospital, a 240-bed university-affiliated tertiary referral center with a 30-bed pediatric intensive care unit (PICU).

METHODS

After institutional human ethics research committee approval, a retrospective study of consecutive patients aged ≤16 yrs who were treated at the Alfred Hospital Hyperbaric Unit from July 1998 to March 2010 was undertaken. Cases were identified by searching the hyperbaric unit database (FileMaker Pro 7.0, Santa Clara, CA, 2004) using age at presentation as a criterion for inclusion. The hyperbaric medical unit database collects patient demographic details, clinical indications for HBOT, hyperbaric treatment tables used, and complications during either treatment or transfer. Missing or incomplete data were obtained from case notes and hospital pathology databases. A review of each patient’s notes was undertaken to determine clinical characteristics, sites of infection, causative pathogens, comorbidities, clinical management, and out-
come not recorded on the hyperbaric database. Data were collected for each indication to determine precipitating events, disease severity, ancillary therapy used, and complications. Primary outcomes recorded were survival with complete resolution of the condition, survival with minor morbidity (repeated débridements or grafting), survival with major morbidity (major débridement or amputation), deaths, and hyperbaric-related complications. A review-specific data extraction form was used so that the same data were extracted from each study and so missing data were clearly apparent. These data were then exported to an Excel (Microsoft, Inc., Redmond, WA) spreadsheet for comparison and analysis.

To indicate the severity of illness in this group, we determined the following: 1) Pediatric Index of Mortality 2 or Acute Physiology and Chronic Health Evaluation (APACHE) 3 score on admission to the intensive care unit (ICU); 2) length of stay in the ICU; 3) number of operative procedures while in the ICU (including débridements and amputations); 4) number of days ventilated; 5) number of days on inotropic support (adrenaline, dopamine, noradrenaline); and 6) the need for renal replacement therapy (continuous venovenous hemofiltration, hemodialysis, peritoneal dialysis).

Statistics. Continuous data were described as either mean (sd) or median (interquartile range) if not normally distributed. Differences between groups for categorical variables were determined using either the chi-square analysis for comparison or Fisher's exact test. The Mann–Whitney U test or Student's t test was used for comparisons between nonparametric and parametric continuous variables respectively. A p value < .05 was considered statistically significant. All analyses were performed using the statistical package STA (College Station, TX).

RESULTS

From 1998 to 2010, 54 children < 16 yrs of age were treated with HBOT at the Alfred Hospital for a range of conditions (Table 1). These 54 patients received 668 treatment sessions (mean, 12.4 sd; 95% confidence interval [CI], 9.2–15.5). Fourteen patients were identified as having been treated while inpatients of an ICU. The 14 intensive care patients completed 57 treatments while ventilated and 69 treatments after extubation. Ventilated patients received significantly fewer treatments than other children (12.4 vs. 3.9, p = .006).

Of the 14 children transferred from an ICU, nine were referred from a PICU and five from an adult ICU. The nine Royal Children's Hospital PICU patients required 40 transfers between the PICU and the Alfred hyperbaric unit. This involved a transfer of 12 km by the Melbourne Ambulance Service and a specialized pediatric emergency transport service with a team of PICU nurses and intensivists. Three patients with acute necrotizing fasciitis were admitted to an adult ICU cubicle (staffed by a PICU nurse and doctor) during the day to facilitate twice-daily treatment and minimize the potential dangers inherent in interhospital transfer.

Details of illness severity of the patients transferred from an ICU are described in Table 2. Probability of death was calculated from the Pediatric Index of Mortality 2 score for pediatric intensive care patients or from the APACHE 3 scores for the children admitted to an adult ICU. Two patients generated both APACHE 3 and Pediatric Index of Mortality 2 scores because they were managed in both the Royal Children's PICU and the Alfred adult ICU during initial HBOT. The median Pediatric Index of Mortality 2 predicted risk of mortality was 12.2% (95% CI, 9% to 24.1%). Patients with necrotizing infections had a lower predicted average risk of mortality than other patients (13.5% vs. 22.9%, respectively). The median APACHE 3 predicted risk of mortality was 18.5% (95% CI, 8.7% to 31.4%). The 14 intensive care patients were treated at the hyperbaric unit a mean of

38.6 hrs (95% CI, 10.3–66.9 hrs) after admission to pediatric intensive care.

The mean length of ICU stay was 13.7 (sd 12.2) days and the mean duration of ventilation was 191.5 (sd 147.1) hrs. Twelve patients (86%) required inotropic support during their initial hyperbaric treatments. The median (95% CI) duration of inotropic support was 62.1 (23.8–298.4) hrs. In the first 48 hrs of intensive care management, four patients were on one inotrope, two patients were on two inotropes, and three on three or more inotropes. During hyperbaric oxygen therapy, 12 patients were on one inotrope and two on no inotropes. Three patients required continuous venovenous hemofiltration and two patients underwent plasmapheresis.

Fourteen ICU patients underwent 62 procedures during intensive care stay and 163 procedures during their hospital stay. Twelve patients (86%) underwent fasciotomy, escharotomy, minor amputation, or skin grafting. Seven patients (50%) underwent major procedures, including laparotomy, extensive débridement, or amputation of limbs.

Table 1. Indications, treatment frequency, and demographics of children treated at the Alfred Hyperbaric Unit, 1998–2010

<table>
<thead>
<tr>
<th>Indication</th>
<th>No.</th>
<th>Age, Mean Yrs (sd, range)</th>
<th>Gender Male/Female</th>
<th>Treatments Mean (sd, range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble injury</td>
<td>4</td>
<td>15.5 (0.8, 14–16)</td>
<td>0/4</td>
<td>6.5 (5.8, 1–12)</td>
</tr>
<tr>
<td>Decompression illness</td>
<td>2</td>
<td>0.29 (0.06, 0.25–0.33)</td>
<td>2/0</td>
<td>1 (0)</td>
</tr>
<tr>
<td>Cerebral arterial gas embolism</td>
<td>21</td>
<td>14.1 (3.2, 2–16)</td>
<td>12/9</td>
<td>9.1 (7.0, 1–22)</td>
</tr>
<tr>
<td>Acute arterial ischaemia</td>
<td>3</td>
<td>14 (1.4, 1.33–15)</td>
<td>0/3</td>
<td>5 (2.6, 2–7)</td>
</tr>
<tr>
<td>Acute severe infection</td>
<td>7</td>
<td>13.1 (4.3, 6–16)</td>
<td>4/3</td>
<td>11.6 (2.8, 1–36)</td>
</tr>
<tr>
<td>Necrotizing fasciitis</td>
<td>3</td>
<td>10.6 (8.5, 0.75–16)</td>
<td>1/2</td>
<td>13.7 (12.4, 6–28)</td>
</tr>
<tr>
<td>Meningococcal Purpura fulminans</td>
<td>5</td>
<td>14 (1.6, 12–16)</td>
<td>4/1</td>
<td>10.2 (6.3, 2–19)</td>
</tr>
<tr>
<td>Nonhealing wounds</td>
<td>4</td>
<td>14.4 (1.5, 13–16)</td>
<td>0/4</td>
<td>31.5 (1.7, 30–33)</td>
</tr>
<tr>
<td>Radiation-induced injury</td>
<td>2</td>
<td>15 (0)</td>
<td>2/0</td>
<td>27.5 (3.5, 25–30)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1</td>
<td>16 (0)</td>
<td>0/1</td>
<td>46 (0)</td>
</tr>
<tr>
<td>Retraumatic osteomyelitis</td>
<td>1</td>
<td>16 (0)</td>
<td>0/1</td>
<td>33 (0)</td>
</tr>
<tr>
<td>Oxycephalies</td>
<td>1</td>
<td>0.5 (0)</td>
<td>0/1</td>
<td>1 (0)</td>
</tr>
<tr>
<td>Total</td>
<td>54</td>
<td>12.76 (4.8, 0.25–16)</td>
<td>28/26</td>
<td>12.4 (11.4, 1–46)</td>
</tr>
</tbody>
</table>

The mean length of ICU stay was 13.7 (sd 12.2) days and the mean duration of ventilation was 191.5 (sd 147.1) hrs. Twelve patients (86%) required inotropic support during their initial hyperbaric treatments. The median (95% CI) duration of inotropic support was 62.1 (23.8–298.4) hrs. In the first 48 hrs of intensive care management, four patients were on one inotrope, two patients were on two inotropes, and three on three or more inotropes. During hyperbaric oxygen therapy, 12 patients were on one inotrope and two on no inotropes. Three patients required continuous venovenous hemofiltration and two patients underwent plasmapheresis.

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Table 1. Indications, treatment frequency, and demographics of children treated at the Alfred Hyperbaric Unit, 1998–2010
Chronic Health Evaluation scores for the children admitted to an adult intensive care unit.

Table 2. Patients treated while being managed in intensive care units

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Age, yrs</th>
<th>Ventilated Treatments</th>
<th>Total Treatments</th>
<th>Pediatric Index of Mortality 2 Probability of Death, %</th>
<th>Acute Physiology and Chronic Health Evaluation 3 Probability of Death, %</th>
<th>Duration of Ventilation, hrs</th>
<th>Length of Pediatric Intensive Care Unit Stay, Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerebral arterial gas embolism</td>
<td>0.25</td>
<td>1</td>
<td>1</td>
<td>33.52</td>
<td>224</td>
<td>9.78</td>
<td></td>
</tr>
<tr>
<td>Cerebral arterial gas embolism</td>
<td>0.33</td>
<td>1</td>
<td>1</td>
<td>15.41</td>
<td>43</td>
<td>2.76</td>
<td></td>
</tr>
<tr>
<td>Necrotizing fasciitis</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>6.64</td>
<td>315.66</td>
<td>23.9</td>
<td></td>
</tr>
<tr>
<td>Necrotizing fasciitis</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>30.91</td>
<td>153.75</td>
<td>8.34</td>
<td></td>
</tr>
<tr>
<td>Clostridial enteritis</td>
<td>1.33</td>
<td>1</td>
<td>1</td>
<td>7.1</td>
<td>172.5</td>
<td>11.2</td>
<td></td>
</tr>
<tr>
<td>Purpura fulminans</td>
<td>1.75</td>
<td>6</td>
<td>7</td>
<td>25.11</td>
<td>237.8</td>
<td>10.95</td>
<td></td>
</tr>
<tr>
<td>Arterial ischemia</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>6.4</td>
<td>374.7</td>
<td>22.75</td>
<td></td>
</tr>
<tr>
<td>Arterial ischemia</td>
<td>12</td>
<td>6</td>
<td>11</td>
<td>32.74</td>
<td>29.1</td>
<td>1.5</td>
<td>3.02</td>
</tr>
<tr>
<td>Necrotizing fasciitis</td>
<td>16</td>
<td>9</td>
<td>36</td>
<td>25.10</td>
<td>12.5</td>
<td>108</td>
<td>7.3</td>
</tr>
<tr>
<td>Necrotizing fasciitis</td>
<td>16</td>
<td>3</td>
<td>6</td>
<td>0.70</td>
<td>12.9</td>
<td>4.5</td>
<td>1.85</td>
</tr>
<tr>
<td>Necrotizing fasciitis</td>
<td>16</td>
<td>4</td>
<td>7</td>
<td>2.80</td>
<td>42</td>
<td>292</td>
<td>31</td>
</tr>
<tr>
<td>Clostridia myonecrosis</td>
<td>15</td>
<td>5</td>
<td>6</td>
<td>2.10</td>
<td>80</td>
<td>3.94</td>
<td></td>
</tr>
<tr>
<td>Purpura fulminans</td>
<td>16</td>
<td>10</td>
<td>28</td>
<td>34.40</td>
<td>20.4</td>
<td>480</td>
<td>41</td>
</tr>
<tr>
<td>Purpura fulminans</td>
<td>16</td>
<td>1</td>
<td>6</td>
<td>9.1</td>
<td>18.5</td>
<td>5.5</td>
<td>7</td>
</tr>
</tbody>
</table>

*Probability of death was calculated from the Pediatric Index of Mortality score for pediatric intensive care patients or from the Acute Physiology and Chronic Health Evaluation scores for the children admitted to an adult intensive care unit.

for 2 hrs 11 mins), whereas acute necrotizing fasciitis, crush injury, and compartment syndromes, including purpura fulminans, were treated with an 18msw table (2.8 ATA for 1 hr 35 mins).

Indications. Indications for treatment were necrotizing soft tissue infections, purpura fulminans, cerebral arterial gas embolism, and arterial ischemia. Six pediatric patients were treated for necrotizing fasciitis. In this group, three polymicrobial necrotizing fasciitis (type 1) and two group A streptococcal necrotizing fasciitis (type 2) and one invasive zygomycosis. Precipitating events in this group included acute lymphocytic leukemia with neutropenia (two patients), acute myeloid leukemia (two patients), spider bite (one patient), and trauma (one patient). The infective organism was Pseudomonas aeruginosa in three cases, group A β-hemolytic streptococcus in two cases, and mucor indicus (one case). Two patients were treated for clostridial infection. Clostridium perfringens type A was the primary pathogen in one case of abdominal wall myonecrosis and C. perfringens type C was isolated in one infant with intestinal ischemia and necrosis (PigBel).

Three patients with severe meningococcal disease with significant peripheral arterial compromise (Purpura fulminans) were transferred for treatment. The causative organism was Neisseria meningitidis serotype B (two patients) and type C (one patient). One 10-month-old infant developed severe limb edema and critical ischemia of her phalanges on both hands 3 days after admission. She received twice-daily treatments over the next 3 days but ultimately required amputation of the right midfoot, left foot, and left hand. A 16-year-old girl developed fulminant meningococcal sepsis with vascular compromise to her hand and feet. She received twice-daily hyperbaric therapy from day 2 of presentation. She required emergency bilateral transtibial amputations, bilateral finger amputations, and débridement and grafting to all limbs, her face, nose, and fingers. A 16-year-old boy developed fulminant meningococcal sepsis with vascular compromise to his hand and feet. Limb salvage was attained but multiple débridements and skin grafting were required. A 3-year-old boy sustained injuries to the right common femoral artery and significant peroneal and limb injuries during an attack by two dogs. Intersate transfer resulted in an ischemia time of 10 hrs before revascularization. Ischemia to the right leg resulted in anterior and peroneal compartment syndrome requiring fasciotomies.

Two patients treated for cerebral arterial gas embolism occurring during cardiac surgery. Details of treatment of the latter two patients have previously been reported (3).

Complications. Hyperbaric side effects are those events specifically related to increased atmospheric pressure and/or oxygen concentrations. No hyperbaric side effects caused ongoing morbidity or disability. In the entire pediatric group, there were 44 events in 668 treatments (6.6%). This included 12 events in 126 treatments (9.6%) for intensive care patients and 32 events in 542 treatments (5.9%) for non-ICU patients. For the intensive care patient group, complications occurred in four of 57 ventilated treatments (7%) and eight of 69 nonventilated treatments (11.6%). The incidence and type of complications were different in the ICU group as compared with the non-ICU group. The most significant complications occurring during HBOT were hypotension, progressive hypoxemia, and central nervous system oxygen toxicity. For intensive care patients, there were three episodes of brief hypotension (2.4%), two episodes of progressive hypoxemia (1.6%), one oxygen toxicity convolution (0.8%), four episodes of anxiety (3.2%), and two episodes of nausea (1.6%). Prophylactic myringotomies were performed in 12 patients before treatment. An oxygen induced convolution occurred in a patient with necrotizing fasciitis of the thigh during the third HBOT treatment at 2.8 ATA. In the non-ICU group, there were 13 episodes of nausea (2.4%), 11 episodes of anxiety (2%), six episodes of grade I or II middle ear barotrauma (1.1%), one central nervous system oxygen toxicity (0.2%), and one brief hypotension (0.2%).

There were two episodes of hypotension during transfer between hospitals, both occurring in children with necrotizing fasciitis requiring manipulation of pre-existing inotropic support. One episode of hypotension occurred during HBOT resulting from battery failure in an infusion pump delivering inotropes. The battery-operated in-
sion devices for transport between hospitals had not been specifically tested for use in a hyperbaric chamber and were exchanged for hyperbaric approved Atom 235 infusion devices (Atom Medical Corporation, Tokyo, Japan) before the treatment. The hyperbaric approved syringe pump failed unexpectedly during compression. Hypotension was brief and treated with a bolus of metaraminol while a new hyperbaric infusion was started.

**DISCUSSION**

Treating pediatric intensive care patients with hyperbaric oxygen presents a number of unique challenges. Ideally HBOT for critical illnesses such as necrotizing fasciitis and clostridial myonecrosis should be administered two to three times a day in the first 24 hrs of illness for maximal benefit. Similarly, the benefit of HBOT is maximal in cerebral arterial gas embolism and acute arterial ischemia from compartment syndromes if the time from insult to treatment is <24 hrs. This obviously significantly impacts on intensive care medical and surgical management of these patients if treatment requires repeated interhospital transfers. In this series, children were most likely to receive HBOT at the appropriate time and for the appropriate duration if the facility is “inhouse” and does not require repeated transfers. Logistic issues resulted in less than optimal HBOT treatment for two patients. A solution explored in this series was to admit the patient to an adult ICU and provide a pediatric intensive care nurse and doctor to provide ongoing care between treatments. This reduced the risks associated with multiple transfers and multiple changes of infusion devices but requires a high level of cooperation between intensivists and treating surgeons.

The indications for HBOT in adults are supported by a large number of clinical series, controlled trials, individual case reports, and consensus statements based on application of physiological principles. In children, however, there are no large randomized controlled trials of hyperbaric oxygen supporting any of the conditions. This series supports the emerging evidence for a significant role for hyperbaric oxygen in acute severe infections, including clostridial myonecrosis and necrotizing fasciitis (4, 5). The primary mechanisms of hyperbaric oxygen in acute severe infections include restoration of normoxia or achievement of hyperoxia in previously hypoxic tissues, inhibition of exotoxin production, enhancement of neutrophil function, and synergistic enhancement of antibiotic activity (6). In this series, there were ten cases of acute severe infection (three cases of clostridial disease and seven cases of necrotizing fasciitis). Two clinical presentations of clostridial disease (clostridial myonecrosis and *Enterococci* *tis necrosins*) were demonstrated in our series. The incidence of *C. perfringens* gas gangrene in children in Australia and New Zealand is unknown but presumed to be rare. In a 10-yr series between 1971 and 1981, Unsworth (7) treated 73 patients (22% mortality) with gas gangrene with hyperbaric oxygen. Seventeen cases were <19 yrs of age with two <2 yrs of age. HBOT has been reported as effective in treating clostridial infection or gas gangrene in pediatric case reports after penetrating injury to the head and neck (three cases) and spontaneous clostridial myonecrosis (three cases) (8–13). *Enteritis necrovicans* (PigBel) is caused by the β toxin produced by *C. perfringens* type C. It is an often fatal illness characterized by hemorrhagic, inflammatory, or ischemic necrosis of the jejunum. Hyperbaric oxygen has not previously been described for treating this condition.

Our series also included six cases of necrotizing fasciitis. Necrotizing fasciitis is rare in childhood and is often caused by group A β-hemolytic streptococcus but also by other aerobic and anaerobic bacteria, including *Clostridium*, *Pseudomonas aeruginosa*, *Bacteroides fragilis*, *Staphylococcus aureus*, *Enterobacter cloaceae*, and *Klebsiella pneumoniae*. Successful treatment of necrotizing fasciitis with hyperbaric oxygen in children has been reported in five small series (5, 14–17). A study by Johnston (14) reported seven cases of necrotizing fasciitis with myonecrosis in neutropenic pediatric oncology patients and demonstrated a synergistic effect of surgical debridement, HBOT, and granulocyte colony-stimulating factor. A study by Golger and Brogan reported low mortality rates in children with group A streptococcal necrotizing fasciitis secondary to varicella (15, 17). They postulated that this was the result of shorter time from inciting event to diagnosis, lack of comorbidities, and absence of immunocompromise in this group.

The use of HBOT in *Purpura fulminans* is controversial (18). *P. fulminans* is a life-threatening disease of children characterized by progressive purpuric lesions of the skin, primarily on the lower limbs, that eventually become necrotic. Acute arterial ischemia can occur as a result of disseminated intravascular coagulation or secondary to compartment syndromes. Hyperbaric oxygen may be of benefit in *P. fulminans* during the phase of acute arterial ischemia, during resolution of ischemia perfusion injury, and during the healing phase. The use of hyperbaric oxygen for pediatric *P. fulminans* has been reported in seven case reports with a total of 23 patients (19–25). In these case reports, limb salvage was possible in 21 of the 23 patients. A study by Rosenthal (23) reported three children with peripheral ischemic lesions, which responded to hyperbaric therapy, but details of two of the patients are sketchy. In our series, two of the three patients with *P. fulminans* required amputation despite early referral for HBOT. It could be argued that the use of HBOT improved the survival rate for these three patients and significantly decreased the degree of debridement and the level of amputation required.

**Outcomes and Complications.** Outcomes from this series are consistent with other series despite differences in the conditions treated. In this series, there were no deaths during treatment, and no patient had major or minor morbidity as a result of HBOT. By contrast, a study by Waisman (19) described 139 pediatric patients aged 2 months to 18 yrs who were treated and reported complete recovery in 93% with two deaths (1.4%) and morbidity in 7.1% (19). Keenan reported on 32 children aged between 3 days and 11 yrs treated with HBOT and reported that 43% of patients were considered normal at discharge, 37.5% had major morbidity as a result of their illness and treatment, and mortality was 12.5%. Twenty-one children were treated for necrotizing infections, nine for carbon monoxide poisoning, and two for iatrogenic arterial air embolism.

In Keenan’s series, there were 47 complications or events occurring during HBOT, including hypotension (63%), bronchospasm (34%), hemoptympanum (13%), and progressive hypoxemia (6%). In our series, the major complications were also hypotension, hypoxemia, and oxygen toxicity. The incidence of oxygen induced seizures (one of 126 treatments [0.8%]) in our series is consistent with the incidence reported in the two pediatric series but higher than the incidence of central nervous system toxicity in adults (26). The central nervous system toxicity incidence in adults treated at the Alfred hyper-
baric unit during the same timeframe was one of 842 treatments (0.12%). In Waisman’s series, hyperbaric oxygen toxicity (one episode of pulmonary oxygen toxicity and one central nervous system oxygen toxicity) occurred in two patients but the number of treatments is not reported so an incidence cannot be calculated.

Despite the illness severity in our cohort, there were only two episodes of hypotension (5%) during 40 transfers. This is consistent with the series reported by Keenan (27) in which the only complication during transport was one accidental extubation (3%). Undoubtedly, the low incidence of complications in this series could be attributed to both the relatively short distances traveled during interhospital transfers, the use of specialized pediatric retrieval units, and the continued input from PICU specialists during transfers and in the hyperbaric environment.

Devices for monitoring of patients and infusion of drugs and fluids requires equipment specifically tested and approved for use in a hyperbaric chamber. Standard intensive care monitors and infusion devices are often unsuitable because they either malfunction during pressurization and depressurization or constitute an unacceptable risk of fire initiation. The infusion devices used for pediatric transfers are not approved for hyperbaric use and contributed to an episode of hypotension in one patient. Infusion devices that have been modified or tested for use in hyperbaric chambers are often not suitable for transport as a result of a limited battery life (28). Exchanging monitors and infusion devices before and following each treatment is time-consuming and also introduced the risk of accidental under- or overperfusion of infotropes.

Limitations. There were several limitations to this study. The study design was retrospective, so we relied on accurate recordkeeping. It is therefore possible that we have underreported the frequency of complications in this cohort of patients. Both the APACHE 3 score and the Pediatric Index of Mortality 2 score of this cohort suggest a group of patients at significant risk of mortality. The conditions treated in our series are significantly different from that described in two other series describing HBOT for children. Currently, the APACHE III scale is designed for use in patients ≥16 yrs of age. Data can be entered for younger patients, but the validity of the sum would be in question. The number of patients was small, and they were a select group who had all been referred to a tertiary center. They may not be representative of children managed with hyperbaric oxygen in general.

Summary and Conclusions. This study demonstrates that children from an ICU can be safely and effectively treated in an adult hyperbaric facility. Treatment of children necessitates transfer other hospitals, which is associated with a small risk but in this series, the incidence of complications during transfer and treatment was low. Fortunately, most of the complications are minor, temporary, and remedial. As such, the need to retrieve children for HBOT should not prevent its use in children.

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REFERENCES

AUTHOR QUERIES

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