Safety of transport and hyperbaric oxygen treatment in critically-ill patients from Padua hospitals into a centrally-located, stand-alone hyperbaric facility

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Abstract

(Bosco G, Garetto G, Rubini A, Paoli A, Dalvi P, Mangar D, Camporesi EM. Safety of transport and hyperbaric oxygen treatment in critically-ill patients from Padua hospitals into a centrally-located, stand-alone hyperbaric facility. *Diving and Hyperbaric Medicine*. 2016 September;46(3):155-159.)

Introduction: Some patients admitted to the intensive care unit (ICU) might require repetitive hyperbaric oxygen treatment (HBOT) while receiving critical care. In such cases, the presence of a hyperbaric chamber located inside or near an ICU is preferable; however, this set-up is not always possible. In Padua, the "*Associazione Tecnici IPerbarici*" hyperbaric centre is a stand-alone facility outside of a hospital. Despite this, selected ICU patients receive HBOT at this facility.

Methods: We retrospectively reviewed the medical records from 2003 to 2013 of 75 consecutive, critically-ill patients, 28 of whom were initially intubated and mechanically ventilated whilst undergoing HBOT. We evaluated the methods adopted in Padua to guarantee the safety and continuity of care during transfer for and during HBOT in this specially-equipped multiplace chamber.

Results: The 75 patients collectively received 315 HBOT sessions, 192 of which were with the patients intubated and mechanically ventilated. The diagnoses ranged from necrotizing fasciitis to post-surgical sepsis and intracranial abscess. We obtained full recovery for 73 patients. Two deaths were recorded not in close time relation to HBOT.

Conclusions: With meticulous monitoring, efficient transport and well-trained personnel, the risks associated with transportation and HBOT can be acceptable for the referring physician.

Key words

Hyperbaric oxygen therapy; intensive care medicine; infectious diseases; fasciitis, necrotizing; transport; clinical audit

Introduction

It is well accepted that high oxygen tension can provide multiple benefits to some critically-ill patients, from rapid inhibition of the production of necrotizing toxins to reduction of the hypoxic marginal zone after a period of acute ischaemia. The raised oxygen tension modulates oedema and cellular infiltration which normally extends deep into the viable tissue. The inflammatory process is, thus, held to a minimum.[1]

In this retrospective study, we investigated the safety of sending ICU patients to receive hyperbaric oxygen treatment (HBOT) to an external facility in the city of Padua. We describe, from both the medical and nursing viewpoints, how to prepare the patient for transfer to the hyperbaric centre and the methods adopted at the "*Associazione Tecnici IPerbarici*" (ATIP) Hyperbaric Medical Centre to ensure continuity of care to critically-ill patients during the administration of HBOT in a multiplace chamber.[2] We reviewed the complications and outcomes experienced during transport and HBOT treatment.[3] ATIP sees all of the most critically-ill patients in the area; thus, the medical professionals are well-acquainted with treatment regimens for critically-ill patients. Three separate ICU facilities from surrounding hospitals can refer patients to ATIP for HBOT. Therefore, cases are varied, from severe soft-tissue infections, post-surgical complications, severe multiple trauma, and the complications of serious systemic infections. These are all pathologies that require a multi-disciplinary approach, and benefit from HBOT starting as soon as possible.[4,5]

Materials and methods

The study was a retrospective chart review approved by the Institutional Review Board of the Biomedical Department at the University of Padua (audit approval number: 12) of 75 consecutive patients (56 male and 19 female; age range 35–55 y; BMI 27–31 $kg \cdot m^{-2}$) referred for HBOT from ICUs at three Padua hospitals from 2003 to 2013. For each patient, disease-related data, number of sessions, duration and pressures of HBOT, clinical outcomes, side effects, and degree of compliance to therapy were collected.

Prior to transfer, each patient was thoroughly evaluated to ensure they were appropriate candidates for HBOT.[6] The patient was first evaluated by an ATIP anesthesiologist in the ICU to assess their clinical status to ensure the absence of contraindications to HBOT and to help ward doctors and nurses to prepare the patient for therapy.[7] A proper clinical evaluation is critical for avoiding complications during HBOT and minimizing risks to the patient.[8] Their history was thoroughly reviewed to identify any potential past conditions that might contraindicate HBOT. Organs and apparatuses affected by an increase in ambient pressure or partial pressure of oxygen were given careful consideration.

Absolute contraindications included: the presence of an untreated pneumothorax, a history of spontaneous pneumothorax, history or diagnosis on admission of sub-pleural emphysematous bullae, a history of retinal detachment, or unstable angina. Relative contraindications can often be evaluated and temporarily managed during transport such as to not delay HBOT.[9,10]

EVALUATION OF THE STATE OF CONSCIOUSNESS

A patient's state of consciousness is evaluated at the bedside since not all patients coming from the ICU have a compromised level of consciousness. This is an important consideration when determining air breaks at pressure and pre-HBOT procedures to be performed (e.g., bilateral myringotomy). In the ICU, the patient may require pharmacological sedation with drugs whose administration must continue during HBOT.[11]

CARDIOVASCULAR EVALUATION

Cardiovascular function is often impaired in sepsis and interferes with the ability to transport the patient out of the ICU. We ensured that both blood pressure and heart rate were maintained within reasonable limits with the use of vasopressors. Systemic venous return and diuresis were evaluated on a daily basis. Heart rate was monitored and history or presence of valvular disease or angina was noted. Patients were also examined for presence and functionality of implanted defibrillators and pacemakers and their compatibility with the hyperbaric environment was evaluated.[12]

RESPIRATORY EVALUATION

Patients coming from the ICU may or may not be breathing spontaneously. If the patient was mechanically ventilated, he/she was assessed to determine if they were completely or partially dependent on the ventilator. In our hands, transport and HBOT require maintaining neuromuscular paralysis combined with adequate sedation for the intubated patient with appropriate drugs. Most patients could be transported on an inspired oxygen fraction (FiO_2) of 0.4.

Pulmonary function tests were evaluated, if available. Chest X-rays were important to verify the integrity of the structures, to confirm the absence of pneumothorax and the correct placement of the endotracheal (ETT) or tracheostomy tube. During HBOT, special attention was given to the ascent phase if the patient required positive end-expiratory pressure (PEEP) to prevent any gas trapping and the subsequent risk of pulmonary barotrauma. Thus, a holistic approach is used in assessing patient eligibility for HBOT. The assessment was conducted to determine both our capacity and ability to manage the patient while simultaneously ensuring continuity of care and minimizing risk to our patients.

The following checklist is commonly completed at the time of initiating transfer:

- Identify the number of infusion pumps and check sufficient quantity of drugs in the syringe(s) for the duration of treatment and any potential delays in transportation.
- Prepare administration of additional drugs to infuse via an IV infusion, as necessary.
- Discontinue unnecessary medication or infusions.
- Provide adequate pain relief for the duration of therapy.
- Suspend parenteral nutrition and whole blood or packed red blood cell infusions to simplify patient management in the chamber.
- Provide access for monitoring arterial blood pressure.
- If the ICU monitoring equipment is compatible with that of the hyperbaric unit, use the arterial line.
- If the monitoring equipment is not compatible, flush the arterial line with diluted heparin and close off.
- Ensure care of the endotracheal tube; nasal intubation rather than oral intubation is preferred because it is more stable and secure.
- Avoid use of a laryngeal mask.
- For tracheostomy tubes, ensure the connections are compatible with the chamber equipment.
- Provide free drainage of a nasogastric tube.
- Assess surgical drains for compatibility (most are) and control the shut-off position.
- Replace ileostomy and urinary drainage bags with fresh ones before sending for HBOT.

The physician and nurse team will continue to take care of the patient inside the pressure chamber. Both team members are ICU credentialed and HBOT trained.

TRANSFER PROTOCOL AND EQUIPMENT

The management of ambulance transport for these critically ill patients has evolved over the years, from manual ventilation with an Ambubag™ for intubated patients in the early years to an Oxylog 2000™ (Dräger) transport ventilator, always under the direct supervision of a critical-care-trained anesthesiologist. During transport, patient monitoring includes ECG, BP (either via an arterial line or non-invasively) and $SatHbO_2$ with a Propaq 106EL (Protocol System Inc.) from 2003 to 2007, then with a Siemens SC9000XL monitor. Drug infusions were continued during transport to the extent and in the manner agreed with the anesthesiologist at the hyperbaric centre, using Fresenius PILOTE C™ infusion pumps. Equipment used in transport and inside the hyperbaric chamber are routinely serviced to ensure all are in ideal working condition.[12]

HYPERBARIC UNIT PROCEDURES

All equipment in the chamber is assembled and tested prior to the patient's arrival to minimize time from leaving the ICU to beginning HBOT. At the ATIP Medical Centre, a hyperbaric

Table 1
Summary of the principal diagnoses; numbers of hyperbaric oxygen treatments (HBOT), including those with patients intubated and ventilated; other treatments and outcomes in 75 patients; DIC - disseminated intravascular coagulopathy; ETT - endotracheal tube

Diagnosis	Patients (*n*)	Initial notes	Other therapy	HBOT sessions intubated and ventilated	HBOT sessions post extubation	Outcomes
Perineal fasciitis	20	5 ETT 3 septic shock	Antibiotics; surgical debridement/drainage; myringotomies	26	15	19 full recovery 1 death
Cervical fasciitis	8	5 ETT 1 tracheostomy 3 septic shock	Antibiotics; surgical debridement/drainage; fasciotomies; myringotomies	20	13	8 full recovery
Gas gangrene	6	All ETT 6 septic shock Further surgery	Antibiotics; surgical debridement	20	35	2 amputations
Abdominal fasciitis (myositis)	15	4 ETT 3 tracheostomies 5 septic shock	Antibiotics; surgical debridement; myringotomies	20	13	15 full recovery
Dehiscent surgical wound	8	2 ETT 1 septic shock	Antibiotics; surgical debridement; myringotomies	23	13	8 full recovery
Mediastinitis	4	2 ETT 1 septic shock	Antibiotics; myringotomies	15	8	4 full recovery
Multiple trauma; acute ischaemia	12	2 ETT 1 septic shock Multiple surgeries	Antibiotics; surgical debridement; myringotomies	30	26	12 full recovery
Intracranial abscess	1	ETT	Antibiotics; myringotomies	20	-	1 full recovery
Meningitis; DIC	1	ETT	Antibiotics; myringotomies	25	-	1 death
Total	75			192	123	73 full recovery 2 deaths

physician received and re-evaluated the patients, transferred the monitoring and infusion systems, and assisted with ventilation by adapting the systems to be compatible with the hyperbaric environment. The mechanical ventilator and perfusion systems used at ATIP were a Siemens Servo 900 E ventilator and two Fresenius Pilote Hyperbaric, both of which were tested for use in hyperbaric environments and resulted in full compliance with European standards.[12] Patients were placed on the ventilator in controlled-volume mode, sedated and paralyzed. The level of PEEP set in the ICU was maintained during HBOT except during decompression when it was decreased to avoid any risk of pulmonary barotrauma and was then immediately restored to its previous level on exiting the chamber.

HBOT was provided in a large multiplace chamber compressed with air (Galeazzi, Zingonia-Italy). All patients were accompanied by an experienced physician who remained inside the chamber throughout the treatment. Oxygen was inhaled through a cuffed ETT or tracheostomy tube. The cuff of the tube was filled with air during HBOT, changing the amount of air in the cuff while changes in chamber pressure occurred to prevent leakage past the cuff or undue pressure on the mucosal lining of the trachea.

The standard HBOT protocol includes a pressure of 254–284 kPa on a daily basis for up to several weeks.[13] Conscious, spontaneously-breathing patients inhaled pure O_2 from a demand-regulated mask for three 25-min periods, interrupted by two 5-min air breaks to minimize the risks of O_2 pulmonary toxicity. For intubated, mechanically ventilated patients, no air breaks were administered. For patients with severe necrotizing soft-tissue infections (NSTIs), the protocol was modified to initiate treatment with five closely-spaced sessions over 48 hours at 284 kPa.[5,8] The precise therapeutic schema was modified on a case-by-case

basis to suit the disease being treated as well as the clinical response achieved. Arterial oxygen saturations before and after HBOT were also monitored.

Results

A summary of the findings is reported in Table 1. Twenty-eight patients were first treated while intubated and mechanically ventilated, and received myringotomies. Subsequently, they received HBOT while breathing spontaneously after extubation.[11] A total of 315 HBOT were given to the 75 patients reviewed, 192 whilst the patients were intubated and ventilated. We did not consider 25 patients rejected for absolute contraindications to HBOT in the same time frame.

Twenty-six patients had NSTIs, of whom 20 had necrotizing fasciitis of the buttock/perineal region and six gas gangrene (GG) of a limb. The diagnosis of GG was made on the basis of fever, tachycardia, severe pain, septic shock, odour, crepitation of tissues, and the presence of gas on X-ray. The finding of Gram-positive rods in a Gram stain confirmed the diagnosis. The patients required placement of multiple decompressive drains and fasciotomies while in the ICU and then they were transferred into the hyperbaric chamber. Surgical debridement with removal of infected and dead tissue was performed prior to HBOT exposure.[14] In 15 patients with abdominal fasciitis, incision and drainage were carried out in the ICU and a temporary colostomy was performed in the operating room to protect the perineal area before HBOT to avoid the passage of stool through the anus and contamination of the perineal wounds.

Eight patients were treated with HBOT for other types of poorly healing surgical wounds. These patients had recently undergone a thoracotomy or a laparotomy and, at the time of surgery, were immunosuppressed. They underwent repeated surgical debridements and subsequently healed. Nine of the thirteen patients with Fournier's syndrome received concomitant antibiotic therapy and surgical debridement(s). The twelve multiple trauma patients were treated with HBOT for ischaemia and/or compartment syndrome. Eight patients with cervical fasciitis and four with mediastinitis were treated with HBOT after surgical debridement. The one patient with disseminated intravascular coagulation suffered from a bacterial meningitis. One patient was diagnosed with an intracranial abscess. The most serious NSTI cases received an initial series of treatments with HBOT at 283 kPa, five times in 48 hours.

All in all, complete recovery was achieved in 73 of the 75 patients. No complications or untoward events occurred during transport or during HBOT. The median time for transportation from the hospital ICU to ATIP in Padua was 21 min (range: 16–29 min). Complications post-therapy included a pneumothorax discovered after return to the ICU. Two deaths from cardiac arrest occurred in patients with Waterhouse-Friderichsen syndrome a few hours after leaving the hyperbaric centre. To 2013, no other in-hospital deaths were reported in this group of patients.

Discussion

The ideal is for the recompression chamber to be situated in or close to the ICU; however, most medical facilities responsible for treating critically-ill patients are not equipped with hyperbaric chambers. Hyperbaric facilities, even if located inside the hospital, are often at some distance from the ICU. Complications compromising patient safety are a major potential risk whilst transporting ICU patients to and fro for remote investigations (e.g., radiological procedures) or treatment such as HBOT. Careful management, using well-established protocols for monitoring and ventilator care by a team skilled in treating ill patients and knowledgeable of the possible complications of HBOT, as in the Padua experience, are pivotal for patient safety.[10]

Critically-ill patients are at increased risk of morbidity and mortality during transport. The transport process itself is associated with a risk of physiological deterioration and adverse events. The incidence of adverse events is proportional to the duration of the transfer, to the pre-transfer severity of illness or injury and to the inexperience of the medical escorts. Risk can be minimized and outcomes improved with careful planning, qualified personnel and appropriate equipment.[15] Many recommendations are available from expert opinion identifying effective 'protective' factors related to the patients, such as equipment checks, accurate preparation of the patient, correct use of protocols, and diagnostic and therapeutic units located within easy reach of the emergency department or ICU.[16] Furthermore, good clinical commonsense is required to decrease adverse events during transport and the risk has to be balanced against the expected benefits of the HBO procedure.

In the present study, the patients were monitored by an intensive-care trained anesthesiologist/hyperbaric specialist at all times during transport, HBOT and return to the ICU. Since none of the patients in this study experienced any transport-related challenges or complications, the ATIP's HBOT protocol has the potential to serve as a prototype for hyperbaric medical centres. Thus, with meticulous monitoring, efficient transport, and well-trained personnel, the risks of transportation and HBOT can be acceptable for the referring physician.

Conclusions

Hyperbaric oxygen treatment can be administered safely to most critically-ill patients in a multiplace chamber provided they are monitored closely with appropriately trained, experienced personnel present. Although the ATIP Medical Centre in Padua is a stand-alone facility, the time of transport

to the intervention was kept short by thorough preparation. No clinical complications during either transport or HBOT were reported in 75 consecutive patients reviewed over a decade, of whom all but two who died made a full recovery.

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Acknowledgements

We wish to thank all our ATIP and hospital medical, nursing and technical colleagues for their skill and professionalism in caring for the patients presented in this report.

Conflicts of interest: nil

Submitted: 07 December 2015; revised 29 February, 05 May and 01 July 2016
Accepted: 13 July 2016

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