Hyperbaric oxygen in the critically ill

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Objective: **To review aspects of hyperbaric medicine pertinent to treating critically ill patients with hyperbaric oxygen in both monoplace and multiplace chambers.**

Data Sources: **Literature review of online databases, research repositories, and clinical trial registries.**

Results: **The search of these resources produced information regarding technical considerations, feasibility, risk, and patient management. Hyperbaric oxygen is used in treating a number of disorders that occur in critically ill patients, including acute carbon monoxide poisoning, arterial gas embolism, severe decompression sickness, clostridial gas gangrene, necrotizing fasciitis, and acute crush injury. Most chambers in the United States treat outpatients with problem nonhealing wounds, and many chambers are not hospital-based. Only a few hyperbaric medicine centers have intensive care unit-level staffing, specialized equipment, a 24/7 schedule, and experience in treating critically ill patients. Not all intensive care unit-related equipment can be subjected to hyperbaric pressurization, and some equipment may increase the risk for fire inside the chamber.**

Conclusions: **Treating critically ill patients with hyperbaric oxygen requires specialized equipment and personnel with intensive care unit skills and knowledge of the physiology and risks unique to hyperbaric oxygen exposure. Like with all medical interventions, it is important to consider the risk vs. the benefit of hyperbaric oxygen for any given critical care disorder, but hyperbaric oxygen can be delivered safely to critically ill patients. Many critical care environments without present hyperbaric oxygen capability may wish to consider offering hyperbaric oxygen to patients with hyperbaric oxygen-approved indications. (Crit Care Med 2011; 39:1784–1791)**

Key Words: hyperbaric oxygenation; critical care; fasciitis; necrotizing; gas gangrene; ventilators; mechanical

Hyperbaric oxygen (HBO_2) is defined by the Undersea and Hyperbaric Medical Society as the inhalation of pure oxygen while the individual is subjected to ≥1.4 atmospheres absolute (atm abs) (142 kPa) or 1.4 times greater than sea level pressure (1).

Most HBO_2 in the United States is provided to outpatients for the treatment of nonhealing wounds (1). The fundamental rationale for HBO_2 in critically ill patients is an oxygen-deprivation state for which clinical experience and evidence support HBO_2. Many of the accepted indications for hyperbaric oxygen (Table 1) (1) occur in patients who are critically ill. However, providers considering the addition of HBO_2 to a critically ill patient's care should also account for technical requirements and patient acuity factors that may influence this decision.

Hyperbaric oxygen is not without risk. Risks from gas volume changes during pressure excursions include middle ear barotrauma (the middle ear space must be insufflated during compression) or pulmonary barotrauma (retained gas in patients with bullous emphysema resulting in arterial gas embolism or pneumothorax during decompression). Ambient oxygen levels can increase risk of fire, and the confined chamber environment can contribute to mortality from this event. In addition, like with patients receiving high concentrations of oxygen at atmospheric pressure, the inhalation of HBO_2 carries risk for oxygen toxicity.

This article discusses the use of HBO_2 in the critically ill, intubated, mechanically ventilated patient, including staffing and equipment considerations, and reviews the published experience in this subject.

Data Sources and Inclusion

Publications of interest were identified through a search of MEDLINE/PubMed using the Medical Subject Headings "hyperbaric oxygenation" and "critical care." In addition, an online search was performed of the research repository at the Rubicon Foundation (http://www.rubicon-foundation.org), which contains articles of interest to hyperbaric providers from publications not indexed in MEDLINE/PubMed as well as abstracts and reports presented at scientific meetings. A search of the terms "critical care" and "ventilator" in this database yielded >400 abstracts, and each was reviewed for relevance. Animal work and non-English publications were excluded as were publications without specific mention of the critically ill, defined here as intubated and mechanically ventilated patients. If the information was presented in abstract form, a further search was performed to locate a subsequent full report, and abstracts are cited here only if no additional information could be found. This search strategy is limited because the search terms may have missed incidental discussions of critically ill patients that were included in publications having other primary topics. However, if the author was aware of publications pertinent to the subject matter of this article outside these search results, this information was included.

The clinical trial registry (http://www.clinicaltrials.gov) was searched for trials incorporating HBO_2 and results were reviewed for inclusion of intubated,

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Table 1. Disorders currently approved by the Undersea and Hyperbaric Medical Society for hyperbaric oxygen (1)

Disorder	Centers for Medicare & Medicaid Services Reimbursement (2)	Author's Estimated Evidence Grading[a]	
		Level of Evidence	Class of Recommendation
Air or gas embolism	Yes	C	I
Carbon monoxide poisoning, including carbon monoxide poisoning complicated by cyanide poisoning	Yes	A	IIa
Clostridial myositis and myonecrosis (gas gangrene)	Yes	C	IIb
Crush injury, compartment syndrome, and other acute traumatic ischemias	Yes	B	I
Decompression sickness	Yes	C	I
Central retinal artery occlusion	No	C	IIb
Diabetic foot ulcer	Yes	A	I
Enhancement of healing in other problem wounds	Yes/no	B	IIb
Severe anemia	No	C	IIb
Intracranial abscess	No	C	IIb
Necrotizing soft tissue infections	Yes	C	IIb
Refractory osteomyelitis	Yes	C	IIa/IIb (depends on site)
Delayed radiation injury (soft tissue and bony necrosis)	Yes	B	IIa
Compromised grafts and flaps	Yes	C	IIa
Acute thermal burn injury	No	A	IIa

[a]Evidence graded according to American College of Cardiology/American Heart Association guidelines (3).

mechanically ventilated patients. The search of these resources produced information regarding technical considerations, feasibility, risk, and patient management.

Facility Requirements and Equipment Selection

General Equipment Considerations. All equipment used inside hyperbaric chambers must adhere to the guidelines of the National Fire Protection Association (NFPA) (4). Chamber fires result in catastrophic consequences (5–7). The primary cause of mishaps is the introduction of prohibited items into the chambers (4), specifically when chamber personnel do not adhere to NFPA fire safety rules. Equipment inside chambers must be intrinsically electrically safe, follow NFPA guidelines, and be tested for the pressures to which they will be exposed.

Hyperbaric Chamber Selection, Location, and Staffing. Hyperbaric oxygen can be offered to critically ill patients in both monoplace (Fig. 1) and multiplace (Fig. 2) chambers, and each type offers advantages for critically ill patients. Monoplace chambers can be located inside the intensive care unit (ICU) (8, 9), where they can be staffed by ICU personnel and are then an extension of the ICU. However, hands-on care cannot be provided to a patient inside a monoplace chamber. Although multiplace chambers do allow hands-on care, experienced staff must be available and willing to care for the patient inside the chamber.

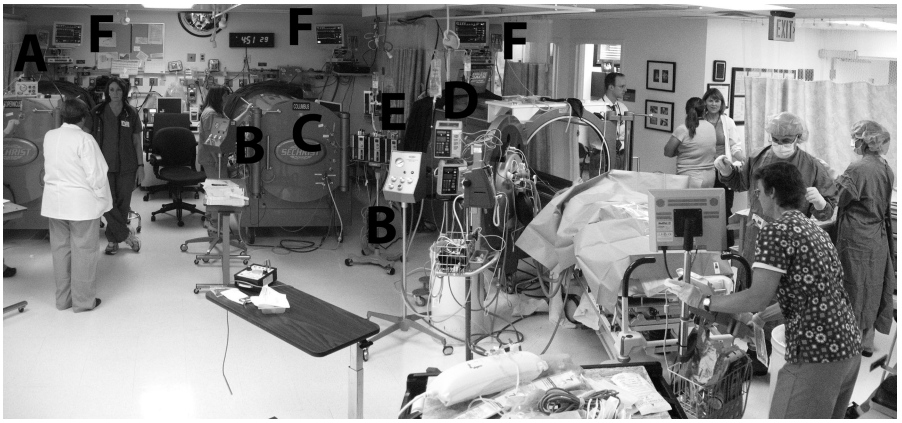

Figure 1. Three intubated critically ill patients with acute carbon monoxide poisoning from operating a propane-powered heater in a tent while hunting. The two patients on the left are compressed in chambers. Before compression in the chamber, the patient on the right needed placement of a central line and arterial catheter (in process) because echocardiography demonstrated global hypokinesis and inotropic support was needed. Magellan (controls are identical to the Omni-vent ventilator) (*A*) (21) and Sechrist 500A (*B*) (20) ventilator control modules are depicted. Each patient required several intravenous infusions perforating the chamber hatches (*C*). Baxter (*D*) (34) and IVAC (*E*) (33) intravenous infusion pumps and physiologic monitors (*F*) are depicted.

Because most hyperbaric chambers are not located within or adjacent to the ICU, the potential benefits of HBO_2 to a critically ill patient must be balanced by the risks from transporting the patient (10–12) as well as the risks from HBO_2 (1). Although treatment of these patients in or near an ICU is optimal (8, 9), safe intrahospital transport practices and qualified HBO_2 caregivers can minimize risk to these patients.

Personnel working as inside attendants of multiplace chambers must be medically suitable for hyperbaric exposure (e.g., able to equalize ears, no claustrophobia, no pulmonary or cardiac disease, etc.) In addition, they must follow safe "diving" practices and adhere to decompression tables (13), because decompression sickness is a risk, albeit low, for inside chamber attendants (14, 15).

Hyperbaric specialty certification for selected caregiver roles is available through the National Board of Diving and

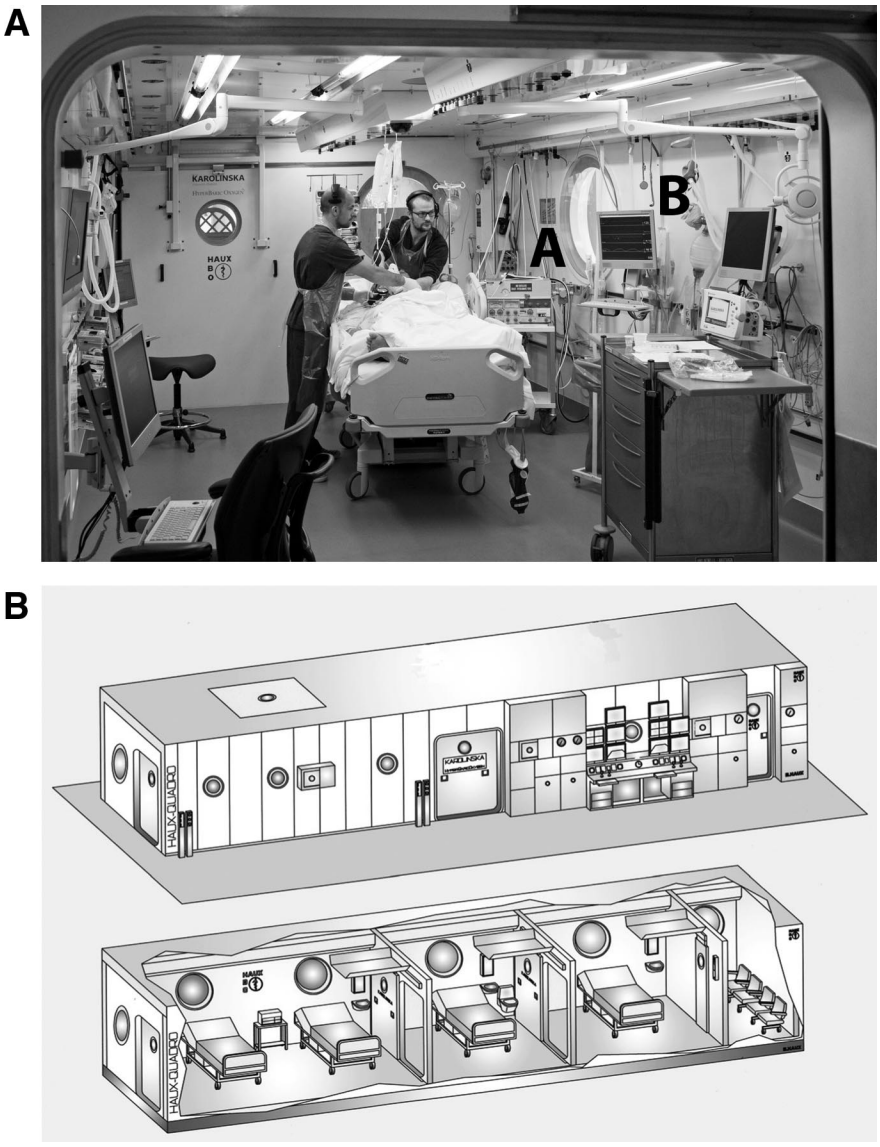

Figure 2. *A,* Multiplace hyperbaric chamber designed and configured for critical care (Quadro 3500; Haux-Life-Support, Karlsbad-Ittersbach, Germany). Like with all multiplace chambers, this chamber is air-filled, and oxygen fractions must be monitored and maintained <0.235. The patient(s) receive oxygen through the ventilator circuit. Exhaled oxygen is evacuated to outside the chamber so it does not raise the oxygen fraction inside the chamber. Depicted (*A*) is a modified Servo 900c mechanical ventilator (Siemens, Erlangen, Germany). Physiological monitors are located inside the chamber (*B*). *B,* Schematic of the Quadro 3500 located at the Karolinska Institute, Stockholm, Sweden. This chamber has four separate, rectangular rooms allowing the simultaneous treatment of multiple critically ill patients with overlapping times for hyperbaric oxygen and at different chamber pressures. (Photo and schematic courtesy of Folke Lind, MD, PhD, Karolinska Institute, Stockholm, Sweden.).

Hyperbaric medical Technology (http://www.nbdhmt.org), including a Certified Hyperbaric Technologist and a Certified Hyperbaric Registered Nurse. Although many centers use Certified Hyperbaric Technologists as chamber operators and inside attendants, the care of critically ill patients requires skills and scope of practice that may exceed that of many Certified Hyperbaric Technologists. Staff supporting critically ill patients during HBO_2 could include Certified Hyperbaric Registered Nurses, physicians, critical care respiratory therapists, and paramedics.

Patient Monitoring. Hyperbaric medicine services that treat critically ill patients must be equipped to monitor the patient to the standards of an ICU, including electrocardiogram, blood pressure, and pulse oximetry. Safety standards dictate that pulse oximetry to monitor arterial oxygen saturation may not be used inside a monoplace chamber (4) and, in any case, are rarely useful because the arterial oxygen tensions are high during HBO_2. However, it is prudent to monitor arterial oxygen saturations of critically ill patients before and after HBO_2.

Physiological monitoring during HBO_2 requires the electrical leads to pass from inside the chamber to outside and then onto the physiological monitor (16, 17). In multiplace chambers (18, 19), a secondary (slave) monitor inside the chamber or outside the chamber but visible through a port allows inside attendants to observe physiological data. The hospital biomedical department should assist in establishing connections between the chamber and the monitors inside and outside the chamber following NFPA guidelines (4).

Mechanical Ventilation. Mechanical ventilation of patients treated with HBO_2 can be hampered by marginal performance of hyperbaric-approved ventilators. In a monoplace environment, the ventilator control modules are located outside the monoplace chamber with the patient circuit located inside the chamber connected to a ventilator block. Tidal volumes and airway pressures are measured inside the chamber with a mechanical spirometer and manometer, respectively. Positive expiratory pressure can be applied using continuous positive airway pressure valves (Accu-PEEP; Vital Signs, Totowa, NJ).

Common ventilators used in the monoplace chamber include the 500A (Sechrist Industries, Anaheim, CA) and the Omni-vent (Allied Healthcare Products, Inc, St Louis, MO). The recently Food and Drug Administration-approved Atlantis Hyperbaric Chamber Ventilator (Providence Global Medical, Inc, Salt Lake City, UT) is also available, and a preliminary, unpublished study of this ventilator found several advantages, including less sensitive controls and setting maintenance during compression and decompression (personal experience). These ventilators are control mode only, so sedation of the patient is often necessary. The 500A performs adequately if the minute ventilation is <12 L/min and positive end-expiratory pressure values are <10 cm H_2O (20). For patients requiring higher minute ventilations, the Omni-vent exhibits better performance (21). All three ventilators have manual controls for adjusting inspiratory flow, inspiratory time, and expiratory time and none has alarms. These ventilators need a separate high-pressure oxygen source (80 pounds per square inch gauge [552 kPa] for the

500A [20] and 120 pounds per square inch gauge [827 kPa] for the Omni-vent [21]) as well as a high-pressure air source if air breathing periods are provided (22). In a limited retrospective review of 100 patients supported by the 500A ventilator, investigators reported that the equipment functioned reliably but found five inadvertent patient circuit disconnects, underscoring the importance of assuring circuit integrity before compression (23).

Ventilators used in the multiplace chamber have similar performance limitations. The Penlon Oxford has been commonly used but developed intrinsic positive end-expiratory pressure and caused air trapping when the respiratory rate was increased (24), and because production of this ventilator stopped in the early 1980s, repair parts are difficult to obtain (25). Several other ventilators have been tested for safety and performance, and although most met safety requirements for the hyperbaric environment (25), performance was marginal, especially under conditions simulating a patient with compromised lung function (26). Even when lung function is normal, the ventilators exhibited tidal volume reductions during pressurization. This finding was mitigated somewhat by using the pressure control ventilation mode as opposed to the volume control ventilation mode (27). More recent performance testing of the modified Siemens Servo 900C (Maquet, Inc, Wayne, NJ) demonstrated that this ventilator could maintain respiratory rate and exhaled tidal volumes in pressure-control mode under hyperbaric conditions (28) and could potentially be used in pressure-support mode as well (29). The Monaghan 225 ventilator has been tested in the multiplace environment and works well (30) and is still supported.

In both monoplace and multiplace chambers, minute ventilation can be monitored by spirometers and manometers or by modified volume monitors (31). During compression, an air-filled endotracheal cuff balloon will be reduced in volume according to Boyle's Law. To prevent this from occurring, the balloon should be filled with sterile saline before compression. After HBO_2, the patient's oropharynx should be suctioned, the saline removed, the cuff filled with air, and safe cuff-to-tracheal tube pressures confirmed (32). In a multiplace environment, air can be added to the balloon cuff during chamber pressurization, but this additional air must be removed during patient decompression to prevent cuff overdistention and possible tracheal damage.

Intravenous Infusion Pumps. The Food and Drug Administration has approved the PLUM A+ Hyperbaric intravenous infusion system (Hospira, Lake Forest, IL) for both monoplace and multiplace chamber use. This pump overcomes the known tubing compliance problem observed in other pumps used with monoplace chambers (33, 34), where compliance of the intravenous tubing between the pump and the chamber hatch leads to tubing expansion during chamber pressurization, affecting drug delivery to patients during HBO_2 (33, 35).

Several pumps have been used and tested within multiplace chambers (36–38). The hyperbaric facility staff should carefully assess any intravenous infusion pump for performance accuracy, suitability, and safety (4, 39). For example, one study reported reductions in inotropic support while using syringe pumps, which might explain hypotension of critically ill patients during compression (38). Some intravenous pumps are powered by lithium ion batteries, possibly posing a risk for fire inside a chamber (40), so they should only be used after due diligence testing for fire safety. However, the NFPA has no current restriction for lithium batteries in the hyperbaric environment (4). Fire hazards from electrical devices can be minimized by purging the cases of electrical equipment with 100% nitrogen or by enclosing them in plastic bags, which can be similarly purged.

Suction. Suction for nasogastric tubes, drains, vacuum-assisted closures, etc., can be applied in monoplace and multiplace chambers (41, 42). The pressure gradient from inside the pressurized chamber to outside the chamber drives the vacuum regulator located inside the chamber.

Chest tubes placed to evacuate fluid without pneumothorax can drain passively or be attached to suction during HBO_2. If there is an active chest gas leak, a one-way Heimlich valve (Bard-Parker Heimlich Chest Drain Valve; Beckton, Dickinson and Company, Franklin Lakes, NJ) may be placed within the chest tube circuit to prevent a pneumothorax in the event of inadvertent exposure to ambient pressure. Closed pleural collection systems should be tested before pressurization, because some closed drainage collection systems can be damaged when subjected to hyperbaric pressure (43). High negative intrapleural pressures can develop during chamber compression, and these pressures can be alleviated by compressing the pressure relief valve of some pleural collection systems (44).

Managing the Critically Ill Patient During HBO_2

Treatment Protocols and Gas Exchange. The HBO_2 treatment protocol (pressure, duration, and number of sessions) selected for the critically ill patient is dependent on the disorder being treated (1). For example, carbon monoxide poisoning may be treated at chamber pressures of 3 atm abs (304 kPa) with up to three sessions in 24 hrs (1, 45), whereas compromised flaps may be treated at 2 atm abs (202 kPa) twice per day for several days (1).

Lung dysfunction influences arterial oxygenation (PaO_2) during HBO_2. For example, an intubated patient needing a fractional inspired oxygen concentration of 0.3 would be expected to have a different PaO_2 at any given dose or pressure of HBO_2 compared with a patient requiring an fractional inspired oxygen concentration of 0.7 (46, 47). In turn, the PaO_2 may influence the efficacy of HBO_2. By adjusting the ventilator parameters and titrating the HBO_2 dose (pressure), clinicians can maintain the patient's PaO_2 between 1000 and 1400 torr (133–187 kPa), analogous to the PaO_2 of individuals with normal cardiopulmonary function exposed to HBO_2 at 2 atm abs while breathing 100% oxygen (46, 47). If the HBO_2 PaO_2 fails to achieve >800 torr (107 kPa), it may be prudent to discontinue HBO_2 until lung function improves to obviate the incremental risk and cost associated with HBO_2 without the therapeutic benefit.

In intubated patients treated with HBO_2, the PaO_2 can be accurately measured in blood aspirated from the compressed patient through a sterile line to outside the chamber (47) by some blood gas machines operating at atmospheric pressure (46–49). Blood gas machines have been adapted for use inside multiplace chambers, allowing measurement at the same ambient pressure as the patient, thereby preventing potential bubbling and preanalytical artifact from decompression (50).

Immediately after exposure to HBO_2, intubated patients often require a higher fractional inspired oxygen concentration than before HBO_2 (51) but within a few

hours after decompression lung function returns to pre-HBO_2 levels (46).

Some HBO_2 schedules require intermittent periods of air breathing to reduce the risk of oxygen toxicity (1, 51–54). Critically ill patients needing fractional inspired oxygen concentration >0.4 to maintain adequate PaO_2 levels can manifest hypoxemia while breathing hyperbaric air, so in those patients, air-breathing periods may need to be omitted (55, 56).

In normal humans exposed to HBO_2 at 2 atm abs (202 kPa), oxygen tensions of muscle and subcutaneous tissue are approximately 200 torr (27 kPa) (57). In patients with acute severe traumatic brain injury, exposed to HBO_2 at 1.5 atm abs (152 kPa), brain oxygen tension was 223 torr (30 kPa) (58).

Transcutaneous Measurements of Oxygen and Carbon Dioxide. Transcutaneous oxygen measurements during HBO_2 are used routinely to make inferences about wound healing success (1, 59, 60) and guide therapy and could be used for this purpose in critically ill patients with hypoxic wounds. Research from healthy adults and from critically ill patients showed that transcutaneous oxygen values were approximately 10% lower than PaO_2 values in ten healthy subjects (61) and in 17 critically ill patients (62). For arterial carbon dioxide tension, the transcutaneous CO_2 tensions were 2–6 torr (0.3–0.8 kPa) higher than the arterial carbon dioxide tension. In 17 critically ill patients, the transcutaneous CO_2 tensions was approximately 10% lower than arterial carbon dioxide tension (62). These limited data suggest that in some critically ill patients, chest transcutaneous oxygen and transcutaneous CO_2 tensions measurements may be acceptable for clinical decisionmaking. For example, in a critically ill patient with iatrogenic arterial gas embolism, the chest reference transcutaneous oxygen demonstrated arterial hypoxemia during protocol-directed hyperbaric air breathing, subsequently causing modification of the HBO_2 protocol (55). Monitoring transcutaneous CO_2 tensions may also be useful to titrate and assess adequacy of mechanical ventilation.

Sedation and Restraints. Critically ill intubated patients treated with HBO_2 often require sedation. There are many different sedation strategies, but continuous infusions of fentanyl and propofol, supplemented with benzodiazepines, are reasonable while monitoring patient hemodynamics. Occasionally, neuromuscular blockade is necessary to facilitate adequate ventilation, to prevent self-extubation, or to limit air trapping, especially if it adversely affects gas exchange.

Unrestrained critically ill patients in the monoplace chamber can dislodge their endotracheal tubes, arterial or venous catheters, or other devices, which may cause serious harm, so restraints are advised for critically ill patients in monoplace chambers. However, because hands-on care can be provided in a multiplace chamber, clinicians can follow ICU restraint guidelines during HBO_2.

Myringotomies. During compression, the air-filled middle ear space will be reduced in volume unless air insufflations or passive equalization can occur. The pressure and volume changes to the middle ear can result in middle ear and inner ear barotraumas. Experts debate whether intubated, sedated patients require prophylactic myringotomies or tympanostomy tube placement before HBO_2 (63–68).

Children. Critically ill children can be treated with HBO_2 in monoplace or multiplace chambers. In one study, hypotension, bronchospasm, hemotympanum, and progressive hypoxemia were noted as complications but were managed by knowledgeable staff (69). Because complications from HBO_2 in critically ill children are rarely reported, this report may not represent the complication rate of other institutions. Input and comanagement by pediatric intensive care are invaluable.

Pacemakers, Intracardiac Defibrillators, and Nerve and Spinal Stimulators. Before compressing patients with implanted pacemakers and intracardiac defibrillators, the manufacturer must specify the device is suitable for hyperbaric compression, including to its maximum pressure limit (70) (Table 2). An intracardiac defibrillator must be interrogated before chamber pressurization to determine the frequency of defibrillation and lead integrity. If the hyperbaric team deactivates an intracardiac defibrillator, personnel and equipment must be available to monitor and treat cardiac dysrhythmias during the interval of intracardiac defibrillator deactivated. The clinician could elect to place transcutaneous pacing pads before compression, although defibrillation inside the hyperbaric chamber may be restricted (see subsequently). Implanted drug delivery devices and spinal stimulators need to be verified by the manufacturer that they may be used during HBO_2.

Defibrillation and Cardioversion. Defibrillation and cardioversion can be performed inside the multiplace chamber as long as NFPA limits for oxygen tension are maintained (4, 71). In the monoplace environment, the chamber must be decompressed and the patient removed before performing defibrillation or cardioversion. If available, the monoplace chamber gas supply should be switched from oxygen to air while decompressing these patients to hasten dissipation of oxygen from around the hyperbaric chamber hatch. All patient garments must be removed before defibrillation because they will be oxygen-enriched and increase the risk of fire if defibrillator-induced ig-

Table 2. Implanted cardiac defibrillator and pacemaker safety in the hyperbaric chamber[a]

Manufacturer	Device	Maximum Rated Pressure (Atmospheres Absolute)	Notes
St. Jude Medical 24-hr support: 1-800-722-3774	All ICDs All pacemakers	7	Safety known only in devices implanted after 1999
Boston Scientific/Guidant 24-hr support: 1-800-227-3422	Confient Telegen Altrua Insignia	5	Safety of older models varies and testing is ongoing; call support line for latest information
Medtronic 24-hr support: 1-800-328-2518	All ICDs All pacemakers	2.5	—
Biotronik 24-hr support: 1-800-547-0394	All ICDs All pacemakers	2.96	—

ICDs, implanted cardiac defibrillators.

[a]Information updated February 2, 2011. Table provided for illustration purposes only. Clinicians must contact the device manufacture directly to verify device compatibility with hyperbaric pressurization.

nition occurs. Patients are cardioverted or defibrillated after opening the chamber hatch and sliding the patient out of the chamber onto the gurney. If switching the chamber gas supply to air is not possible, then at least 40 secs must elapse for oxygen to dissipate before defibrillation (72).

Other resources are available that provide practical guidance in managing critically ill patients' monoplace and multiplace hyperbaric chambers (8, 50, 73–79).

Critical Care and Hyperbaric Oxygen Experience

At Loma Linda, CA, from 1981 to 2003, 199 intubated critically ill patients were treated with HBO_2 in monoplace chambers for necrotizing infections, carbon monoxide poisoning, compromised surgical flaps/grafts, and acute arterial ischemia. There was no HBO_2-related mortality attributed to this group (80).

At LDS Hospital, Salt Lake City, UT, from 1986 to 2006, 182 intubated critically ill patients were treated with HBO_2 in monoplace chambers (representing 1281 HBO_2 sessions in 61 females and 121 males; age, 44 ± 19 years; age range, 2–83 yrs) (81). Patients had necrotizing fasciitis, carbon monoxide poisoning, crush injury, gangrene, arterial gas embolism, mucormycosis, arterial insufficiency, failing flaps, osteomyelitis, or radiation necrosis. Myringotomies were done in 66 patients (until 1992) and no myringotomies in 116 since 1992. Of the group, 108 patients (59%) had Acute Physiology and Chronic Health Evaluation II (82) scores of 17.6 ± 7.5 (range, 6–44). The mean number of separate intravenous infusions per patient was 3.8 ± 1.8 (range, 1–11). Of 154 patients (85%) with outcome data, 27 died from their disease or withdrawal of support. Complications necessitating decompression from the chamber occurred in 35 of 1281 compressions (2.7%) and included ventricular tachycardia/fibrillation (n = 1), hypoxemia with air breathing (n = 2) (55), arterial line problems (n = 5), ventilator circuit problems (n = 8), ventilator malfunctions (n = 2), seizures (n = 3), air trapping and hyperinflation with hypotension (n = 4), inadequate sedation (n = 5), and arrhythmias (n = 4). One patient being treated for iatrogenic gas embolism, which caused acute lung and cardiac injury and subsequent profound hypoxemia, achieved hyperoxic PaO_2 values with HBO_2 but worsened abruptly with decompression to atmospheric pressure. This patient had a hypoxic cardiac arrest on exiting the chamber (55). Some of these problems could have been managed at pressure if the patients had been treated in a multiplace chamber.

Over a 32-yr period, 200,000 HBO_2 sessions were provided at Long Beach Memorial Medical Center, Long Beach, CA. Of this total, 10,000 sessions were rendered to patients admitted to the critical care units. Reasons for withholding HBO_2 included need for an fractional inspired oxygen concentration >0.5, hypotension requiring vasopressors, hypertension treated with intravenous vasodilators, hyperthermia, status epilepticus, tension pneumothorax, need for a fluidized bed, morbid obesity, end-stage malignancy, and concomitant intralipid infusions, although rationale for this final exclusion was not provided (83). Withholding HBO_2 for intralipid infusion is not standard practice at many HBO_2 facilities.

Patients with acute severe traumatic brain injury have been treated with HBO_2 in both monoplace and multiplace chambers safely (8, 58, 84–86). In a prospective trial of 69 patients with severe traumatic brain injury randomized to HBO_2 or to normobaric oxygen, brain tissue PO_2 was 223 torr (30 kPa) vs. 86 torr (11 kPa) (58). In addition, cerebral blood flow and cerebral metabolic use of oxygen were greater in the HBO_2 group. Bronchoalveolar lavage samples showed no evidence of oxygen toxicity in the HBO_2 group (58).

CONCLUSION

Critically ill patients can be treated with HBO_2 in both monoplace and multiplace hyperbaric chambers. To deliver safe care to critically ill patients, the chamber environment needs to support critical care while adhering to NFPA guidelines (4), and the staff need to be trained and experienced in critical care management. Optimally, the chamber needs to be configured similarly as the ICU or be located within the ICU. Like with all medical interventions, it is important to consider the risk vs. the benefit of HBO_2 for any given critical care disorder, but HBO_2 can be delivered safely to critically ill patients. Many critical care environments without present HBO_2 capability may wish to consider offering HBO_2 to patients with HBO_2-approved indications.

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