A pro/con review comparing the use of mono- and multiplace hyperbaric chambers for critical care

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Abstract

(Lind F. A pro/con review comparing the use of mono- and multiplace hyperbaric chambers for critical care. *Diving and Hyperbaric Medicine*. 2015 March;45(1):56-60.)

Hyperbaric oxygen treatment (HBOT) of critically ill patients requires special technology and appropriately trained medical team staffing for '24/7' emergency services. Regardless of the chamber system used it is essential that the attending nurse and critical care specialist understand the physics and physiology of hyperbaric oxygen for safe treatment and compression/decompression procedures. Mechanical ventilation through endotracheal tube or tracheotomy is hampered by the increased gas density and flow resistance with risks of hypoventilation, carbon dioxide retention and oxygen seizures. Ventilation should be controlled and arterial and end-tidal carbon dioxide levels monitored. Haemodynamically unstable patients require careful risk-benefit evaluation, invasive monitoring and close supervision of inotropes, vasopressors and sedative drug infusions to avoid blood pressure swings and risk of awareness. Two distinctly different chambers are used for critical care. Small cost-efficient and easy-to-install acrylic monoplace chambers require less staffing and no inside attendant. Major disadvantages include patient isolation with difficulties to maintain standard organ support and invasive monitoring. Monoplace ventilators are less advanced and require the use of muscle relaxants and excessive sedation. Intravenous lines must be changed to specially designed IV pumps located outside the chamber with chamber pass-through and risk of inaccurate drug delivery. The multiplace chamber is better suited for HBOT of critically ill patients with failing vital functions and organ systems, primarily because it permits appropriate ICU equipment to be used inside the chamber by accompanying staff. Normal 'hands-on' intensive care continues during HBOT with close attention to all aspects of critical patient care. A regional trauma hospital-based rectangular chamber system immediately bordering critical care and emergency ward facilities is the best solution for safe HBOT in the critically ill. Disadvantages include long-term commitment, larger space requirements and higher capitalization, technical and staffing costs.

Key words

Hyperbaric oxygen therapy, intensive care medicine, pressure chambers, safety, review article

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Introduction

This review is influenced by 25 years of clinical hyperbaric work by the author as a specialist in anaesthesia and intensive care medicine, with research and development of hyperbaric medicine in a hyperbaric oxygen treatment (HBOT) facility with multiplace ICU capability and 24-hour emergency services in the academic university trauma hospital setting. Since 2006, the Karolinska University Hospital has used a large four-lock rectangular chamber immediately bordering the ICU, staffed and equipped for simultaneous full intensive care of up to four critically ill adult or paediatric patients with failing vital functions.[1] In cooperation with manufacturers, Germanischer Lloyd and the Karolinska Biomedical Engineering Department, many of the medical devices like infusion pumps, patient monitors, the patient data management system, defibrillator and ventilator have received CE approval for use within the hyperbaric chamber.[2]

Since 1992, the Karolinska has also had monoplace chambers in daily clinical practice, introduced for daily elective treatments in spontaneously breathing patients.

Monoplace chambers have been found valuable for emergencies, traumatic ischaemic conditions, neurosurgical infections and also in spontaneously breathing intensive care patients. This experience of monoplace practice has been augmented by repeated visits to hyperbaric units in Salt Lake City, Long Beach, San Pablo and other reputable American centres, generally run by specialists in pulmonary critical care or emergency medicine, where monoplace chambers are used extensively.

A large number of experienced and dedicated nurses, technicians and colleagues at the Karolinska have helped to develop our multiplace and monoplace programmes to ensure that HBOT can be performed safely in patients of all ages. With appropriate monoplace chamber pass-throughs and infusion pumps, drugs can be administered continuously intravenously and through an epidural catheter during HBOT. This makes it possible to combat pain, anxiety and nausea effectively. The monoplace has also been used to treat many newly extubated intensive care patients, especially in small children who will not easily be persuaded to breathe through a mask or a hood in the multiplace chamber. An intensive care nurse can accompany the child in the monoplace chamber and deliver all drugs manually for constant drug delivery and to keep lines from clotting. However, we have not used the monoplace in intubated patients nor in unstable patients or 'when in doubt', e.g., worries over pulmonary oedema or immediately after a central line has been inserted (with risk of pneumothorax), when we have taken the option to use the multiplace chamber.

With this background of personal experience and having never treated an intubated, unstable patient in a monoplace chamber, this pro/con review contrasts mono- and multi-place hyperbaric chambers for critical care. My views on how to design a new hospital-based hyperbaric facility with ICU capabilities were presented at the 2012 European Committee for Hyperbaric Medicine Consensus Conference in Belgrade; and again at the 2013 Conference on Diving Physiology and Hyperbaric Medicine in Japan.[3,4]

Background

HBOT has been used clinically for critically ill patients for over 60 years,[1,5–11] and the two distinctly different types of chambers contrasted in this review have also been available since the 1960s. In treating the critically ill patient safely with HBOT, like with many other medical interventions, it is important to do a risk/benefit assessment. This requires unique competence both in the complex pathophysiology of the conditions treated as well as knowledge of HBOT physics and physiology to avoid possible complications unique to HBOT exposure. Ventilation, whether spontaneous or ventilator-assisted, is hampered by the increased gas density at depth. This does not affect oxygen (O_2) uptake but can lead to hypoventilation. At 283 kPa pressure, the three-fold density causes a doubling of flow resistance with a need for change in ventilator settings to avoid harmful high pressure, hypoventilation and carbon dioxide (CO_2) retention which, in turn, increases cerebral blood flow and the risk of O_2 seizures. Ventilation should be well controlled including careful monitoring of arterial blood gases and end-tidal CO_2.[12]

Haemodynamically unstable patients require careful risk-benefit evaluation and close supervision due to, for example, O_2-induced systemic vasoconstriction with changes in preload and afterload. During HBOT, patients with hypervolaemia and/or reduced left ventricular function are in danger of acute cardiogenic pulmonary oedema, especially if treated supine. Patients in septic shock risk hypovolaemia after HBOT when vasoconstriction and thoracic blood pooling cease. Short-term, reversible hypoxaemia is frequently seen immediately after HBOT due to atelectasis and changes in central haemodynamics.[13]

Time to treatment is crucial for acute HBOT indications, for example, cerebral arterial gas embolism in a comatose diver after free ascent or in the anaesthetized patient not waking up after open heart surgery; the burns victim with carbon dioxide (CO) and cyanide poisoning and inhalation injuries; the unstable, septic fasciitis patient with multi-organ failure or the motorcyclist with multiple trauma with crush injuries, arterial damage with ischaemia or with reperfusion injury after vascular reconstruction. In general, the earlier these patients are treated, the better the outcome.

Critical care HBOT 24/7 is often not available in hospital-based HBOT centres due to lack of funding, experience, specialized equipment, intensive care unit cooperation, trust between specialties, staffing, etc. The political and historical background of each hospital, region, country and continent has influenced the location and critical care capabilities of available HBOT facilities. The design of a HBOT facility often depends on the individual physician in charge, accepted indications and how sick the patients are, i.e., whether emergency care is required. We therefore have a multitude of different solutions globally regarding the availability of HBOT and the use of mono- or multiplace hyperbaric chambers for critical care.

MULTIPLACE CHAMBERS

Multiplace steel chambers are designed with two or more independent compartments (locks) to accommodate patients and hyperbaric staff who may enter and exit the chamber via an adjacent lock during therapy. The multiplace chamber is compressed with air. Patients are provided with oxygen via an individualized built-in breathing system, usually a mask or head hood or by mechanical ventilation via an endotracheal or tracheostomy tube. Dedicated air compressors and large low- or high-pressure receivers provide the chamber air supply. A specialized fire suppression system with water tanks for each lock is necessary. A multiplace chamber allows appropriate ICU equipment to be used bedside/inside the chamber by the accompanying staff.

MONOPLACE CHAMBERS

Monoplace chambers are designed for single occupancy, usually constructed of see-through acrylic with a pressure capability of 304 kPa and pressurized with 100% O_2, which allows the patient to breathe comfortably without a mask or hood. The high-flow O_2 requirement is ideally supplied via a hospital's existing liquid O_2 system. Operators and medical staff maintain communication with the patient via intercom. Technical inventions and modifications of the medical equipment allow critically ill and ventilator-dependent patients to undergo HBOT without accompanying staff.

Multiplace chamber advantages

- Hands-on patient attendance and bedside medical and nursing supervision of all aspects of evaluation and treatment;
- Immediate medical interventions by the inside attendant, including endotracheal suctioning, resolving acute airway obstruction, defibrillation or a chest tube insertion; additional staff can be locked in during medical emergencies;
- Not having to change bed or monitoring in modern chambers with spacious design and wide doors;
- Uninterrupted mechanical ventilation via a battery-powered, modern, state-of-the-art ICU ventilator that does not have to be disconnected throughout transport and HBOT;
- Uninterrupted, continuous and reliable infusions via battery-powered infusion pumps approved for hyperbaric use that do not have to be disconnected during transport or HBOT; septic or otherwise haemodynamically unstable patients, in particular, require accurate haemodynamic monitoring, uninterrupted vasoactive drug infusions and continuous blood, fluid and electrolyte therapy during treatment; there is a particular need for close attention of inotrope and vasopressor infusions during pressurization of the chamber when remaining gas in a syringe and/or tubing may reduce or even cease drug delivery which is not detected by the syringe pump but can be corrected manually by accompanying staff;[14]
- Less risk of barotrauma and iatrogenic air embolism during decompression than in a monoplace, as volume changes in an air-filled endotracheal cuff or in IV containers can be corrected immediately;
- Defibrillation if need be with battery-powered defibrillator;
- Catastrophes: a trauma centre will normally be best prepared and equipped to take care of several critically ill patients simultaneously, e.g., a family with CO poisoning and smoke inhalation injuries found comatose inside a burning apartment;
- There are more options regarding tables with choice of pressure and treatment gas; it is also possible to conduct a neurological examination to help guide treatment in severe cases of decompression illness.

Multiplace chamber disadvantages

- High capitalization, technical and staffing costs;
- Large space requirements, difficult to install close to the ICU in old hospitals, and a long-term commitment; once installed it is difficult and expensive to change facility and location due to weight, dimensions and associated compressor, fire extinguishing and other systems;
- Limited availability of multiplace HBOT facilities with ICU capability and 24-hour emergency services;
- Many multiplace chambers in use today are not located in regional centres; often they are in a less specialized hospital without intensive care resources and not accustomed to multidisciplinary treatment programmes; competence will limit referrals;
- Critical care and emergency patients 'disturb' regular planned HBOT practice in the multiplace; depending upon configuration and size there will be a conflict of interest to immediately prepare for an emergency treatment and stop an ongoing elective treatment;
- Risk of decompression sickness (DCS) in the attending staff; more staff are needed with repeat sessions with the risk of not having staff available;
- Risk of barotrauma and iatrogenic air embolism; e.g., during pressurization and decompression the endotracheal cuff can harm the trachea due to overpressure or leak; during decompression, expanding gas in a plastic or glass bottle can give rise to venous air embolism;
- Increased risk of nosocomial infection; special cleanliness considerations, hygiene procedures and technical solutions are needed.

Monoplace chamber advantages

- Cost-efficient delivery of HBOT (capitalization and operating costs) with less financial risk so that more hospitals in less densely populated areas can deliver HBOT in a timely fashion;
- Flexibility, they can be installed within an existing ICU if sufficient space is available;
- Require less staffing and no inside attendant, i.e., no risk for DCS;
- Better hygiene and less risk of nosocomial infection;
- Excellent delivery tool in awake spontaneously breathing children; after extubation, children can be treated together with accompanying nurse who can manually deliver most IV drugs, epidural pain relief, etc.

Monoplace chamber disadvantages

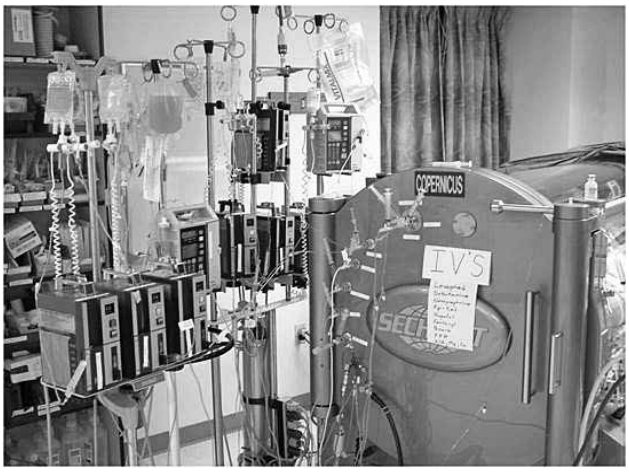
- Patient isolation
- Use of muscle relaxants and/or restraints to prevent the patient from pulling out tubes, lines, catheters, etc;
- Risk of awareness from inadequate sedation and analgesia whilst being unable to move or communicate their anxiety, pain and discomfort;
- Hypotension if too much sedation, especially in

comatose patients from CO/cyanide poisoning or cerebral arterial gas embolism and in the unstable patient with necrotizing infection coming directly from the operating room;
- Pneumothorax is difficult to treat and diagnose; chest tubes with negative pleural suction or a one-way Heimlich valve can be used, but a pneumothorax under pressure becomes a tension pneumothorax and medical emergency during decompression with major impairment of respiration and/or blood circulation;
- Acute airway obstruction; the mechanically ventilated, intubated patient often requires frequent endotracheal suctioning which is very difficult in a monoplace;
- Difficult to monitor and correct the patient's vital functions throughout the HBOT session, e.g., diuresis, fluid and electrolyte status, arterial blood gases and end-tidal CO_2;
- Change of ICU bed to an uncomfortable mattress on stretcher with risk of pressure ulcers;
- Risk of acute cardiogenic pulmonary oedema, especially if treated supine;
- The oxygen environment and fire hazard limits the use of a variety of specialized critical care equipment inside the chamber;
- Mechanical monoplace ventilators located inside the chamber lack modern control, modes and settings;
- Infusion pumps are located outside the chamber; inaccurate drug delivery especially with low delivery rates becomes a real problem in unstable patients; tubing compliance during compression and decompression may affect fluid volumes delivered by the pump since it has to overcome the chamber overpressure;[15]
- Limited number of pass-through tubes for conveying IV fluid to a patient under pressure;
- Bolus doses of drugs are difficult unless the IV line is dedicated to that drug;
- Suction can only be accomplished by specially adapting existing hospital equipment;[16,17]
- Time-consuming changes of lines before and after treatment, with consequent risk of contamination.

Discussion

Regardless of chamber system, HBOT of critically ill patients should be regionalized to maintain quality and cost effectiveness with good helicopter and other emergency transportation services.[3,4] Hyperbaric intensive care should be performed within a hospital and be supervised by properly trained and experienced medical staff with intensive care skills. Out-patient hyperbaric chambers are not recommended even though many emergencies are still being treated in such facilities because of lack of alternatives. The chamber should preferably be located in close proximity to the ICU to minimize the risk of transport-, equipment-, staff- or patient-related problems. It should be operated and maintained according to written guidelines and regulations. In Europe, a "*European code of good practice for HBO therapy*"[18] (to be revised 2015, <www.ECHM.org>) should be followed. If appropriate safety precautions are not strictly adhered to, catastrophic accidents may continue to occur regardless of chamber type!

Figure 1
Critical care in a monoplace chamber; intensive care requires modifications of chamber and equipment (courtesy of Lindell K Weaver, Salt Lake City, USA)



A regional trauma hospital-based, large, three to four lock, multiplace, rectangular chamber immediately bordering the ICU, staffed and equipped for full intensive care is the ideal (see front cover photo of the Karolinska facility). In reality, this is uncommon and it is evident that appropriately medically-equipped monoplace and smaller multiplace chambers in less ideal locations are being used to treat critically ill and ventilator-dependent patients. Critically ill patients can be managed in many different settings providing the facility is staffed with physicians, nurses and therapists skilled in their care and possessing a thorough understanding of hyperbaric physiology and the medical techniques unique to HBOT. Several modifications of chamber and equipment have to be implemented, which requires technical competence.[16,17]

The monoplace chamber, although less well suited for intensive care can be used to treat critically ill patients and permit clinical research (Figure 1). The safe treatment of severe, traumatic brain injury patients, including monitoring of cardiovascular and ventilatory parameters as well as intracranial pressure, brain tissue oxygen levels, brain temperature and cerebral microdialysis, provides an example of what is possible using a monoplace chamber.[19] This required specially modified equipment for ventilation, monitoring and management of the patient. Ventilator-dependent neonatal patients with acute hypoxic ischaemic encephalopathy and necrotizing enterocolitis have also been treated in the monoplace chamber, given bag-valve-mask ventilation by an accompanying neonatologist during the treatment.[20]

A hyperbaric critical care patient data management system should be in place in order to provide continuous bedside and remote clinical patient documentation and information.[2–4] At the Karolinska, data are fed into a central clinical information management system to monitor, display trends and record data of vital parameters, ventilator settings and drugs. This has improved the quality of care during HBOT and facilitated research and development in hyperbaric medicine.

Conclusion

The multiplace chamber is better suited than a monoplace chamber for HBOT of critically ill patients with failing vital functions and organ systems, primarily because it permits appropriate ICU equipment to be used inside the chamber by bedside staff accompanying the patient in the chamber.

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Acknowledgement

I would like to thank Lindell K Weaver, Salt Lake City, for his support and critical reading of this paper.

Submitted: 09 November 2014; revised 31 January 2015
Accepted: 03 February 2015

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Front cover photo (courtesy Dr Lind, with permission) shows hands-on critical care in the Karolinska multiplace chamber. The four-lock rectangular chamber immediately borders the ICU and is staffed and equipped for simultaneous full intensive care of up to four critically ill patients with failing vital functions, also in children. In cooperation with manufacturers, technical supervisory organization and classification society Germanischer Lloyd and the Karolinska Biomedical Engineering Department many of the medical devices used have received CE approval for use within the hyperbaric chamber.