MONOPLACE HYPERBARIC CHAMBER SAFETY GUIDELINES

Report to the Hyperbaric Chamber Safety Committee of the Undersea and Hyperbaric Medical Society

Edited by

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CHAPTER I: INTRODUCTION

Michael B. Strauss, M.D.

Genesis of the Guidelines

1. The Undersea and Hyperbaric Medical Society (UHMS) was asked by its membership to develop a set of safety guidelines for both monoplace and multiplace hyperbaric chambers. In 1986 the Safety Committee of the UHMS, under the chairmanship of Dr. Keith Van Meter, was given this charge. Independently, Mr. James McCarthy, P.E., at the Navy Experimental Diving Unit, Panama City, FL, generated two manuscripts, *Monoplace Chamber Safety Document* and *Multiplace Chamber Safety Document*. This monumental work by a single author was presented to the Safety Committee for review.

2. At the Safety Committee Meeting of the 1987 Annual UHMS Meeting, Dr. Van Meter nominated Dr. Michael Strauss to coordinate a subcommittee to review Mr. McCarthy's document, make recommendations, and revise it as necessary. At that meeting volunteers were sought to assist Dr. Strauss in completing the revision, which included Jim McCarthy, Dick Clarke, Judy Johnson, Ted Gurnee, and Diana Greenberg.

3. The subcommittee reviewed Mr. McCarthy's document and thought it was a good foundation for rewriting a comprehensive document on monoplace chamber safety. A notebook format with 10 chapters was proposed. The subcommittee members agreed to contribute chapters in their areas of expertise.

4. Subsequently, the Subcommittee was expanded to include George B. Hart, Lindell Weaver, and Valerie Messina; several original members resigned because of other commitments. Finally, at the request of Dr. Strauss and with the approval of the UHMS Safety Committee, In June 1989, Dr. Weaver agreed to share the editorial responsibility for the guidelines.

Guideline Objectives

1. The guidelines are designed to provide basic information regarding safety and setup of a monoplace hyperbaric chamber facility, and patient management. The guidelines are dynamic and subject to change as developments in the field occur.

2. This document is expected to fulfill the following objectives:

a. To orient the health care professional to the monoplace hyperbaric chamber, its configurations, and its history.
b. To describe the regulations that pertain to monoplace hyperbaric oxygen (HBO_2) chambers.
c. To list requirements for setting up a monoplace HBO_2 facility including gas supply, exhaust systems, and grounding.
d. To describe the monitoring and life support capabilities of the monoplace hyperbaric chamber.
e. To explain system care and maintenance for the monoplace HBO_2 chamber.
f. To demonstrate an approach to patient preparation and procedures.
g. To review administration procedures and record keeping.

History of the Monoplace Chamber (George B. Hart, M.D.)

1. Junod (1) first described the clinical use of a monoplace hyperbaric chamber in 1834. The chamber was a hollow sphere of copper measuring 1.4 m in diameter. Remarkably, the first patients were treated at hypobaric pressures with the internal working pressures lowered to 500 mmHg air absolute. He discarded this technique when the patients consistently became short of breath and cyanotic, and used pressures of 2–4 atm abs air with more apparent success.

2. Following Junod, monoplace chambers were relegated to treating decompression illness until Churchill-Davidson and Thomlinson (2) reported their use as a radiosensitizer concurrently with radiotherapy in 1955. It is noteworthy that "a modified naval diving recompression chamber" was used in this report as assisted by the "surgeons and diving officers of HMS *Vernon* and HMS *Reclaim*." This was a unique human trial as it is the first clinical trial using anesthetized patients in a monoplace chamber. Each patient was monitored with an electrocardiograph and electromyograph. The middle ear was protected against baro-

trauma by elective myringotomy. The spontaneously breathing patients' respirations were monitored by a thermistor mounted on the outlet of the carbon dioxide-absorbing canister.

3. The majority of the monoplace varieties at that time were cylindrical, made mostly of metal with small view ports, the chamber measuring 26–36 inches in diameter by 7–8 feet in length. A patient tray is required in this type, usually of similar length to gain ingress and egress, thereby requiring a room of at least 16 feet in length for proper access. The Vickers hyperbaric oxygen bed was designed to operate in a smaller space than the preceding and was accomplished by placing the patient in a seated position using a bivalve top, hinged from the bottom. The first prototype (3) was installed in Westminster Hospital (England) in 1964. The English have since stopped production of this model but its configuration has found favor in the USSR and they mass produce a similar model.

4. An important contribution during this period of development was configuring the hull with clear acrylics, thereby allowing improved visual contact of the patient. Those authors inspired the development of this particular design when they set out the following goals (4):

"a. Production of a mobile chamber, able to withstand at least 1 atm above ambient, which would allow continuous visual and auditory contact with the patient.

"b. Elimination of any feature that would make the conscious patient unwilling to forego this form of treatment.

"c. Elimination of the risk of explosive decompression, which might endanger bystanders and affect the patient because of a sudden drop of pressure.

"d. Development of a system of pressurization that would at least minimize ear and sinus pain or damage (otic/sinus barotrauma). These syndromes are caused by difference of pressure between the environment and the sinus and middle-ear cavities.

"e. Provision of adequate ventilation, to give full oxygenation and prevent retention of water vapor and carbon dioxide inside the chamber."

Ambulances were reportedly equipped with these plastic chambers in the early 1960s to attend carbon monoxide intoxication (5) and myocardial infarction (6).

5. The portability of the monoplace chamber made it suitable for close support of military diving activities from World War I to the present. Recently, successes have been reported in treating commercial (7) and sport divers (8,9) by transporting the chamber by helicopter to the stricken diver and flying him back under pressure to the larger treatment facility.

6. *Several significant chamber accidents have occurred with monoplace chambers* (time and location are approximate):

a. 1960s in the United States, an acrylic hull exploded injuring (minor laceration) an observer (radiotherapist). The patient died some time later from the malignancy which was being treated at the time of the accident. This accident was the stimulus for the development of the double hulled acrylic chamber to prevent injury in the immediate area (10).

b. 1960s in Mexico, a telescoping monoplace chamber exploded at unknown operating pressures with the occupant dying from the event (11). This type of collapsible (metal) chamber has been discontinued by the manufacturer.

c. 1960s in the United States, patient suffered a runaway pacemaker after reaching 2.5 atm abs pressure. The patient was decompressed emergently due to hemodynamic compromise resulting from a heart rate of 240 beats/minute. The attending Naval Medical Officer (thoracic surgeon) rapidly excised the malfunctioning pacemaker and replaced it with a temporary model. The manufacturers were notified of this occurrence and now produce permanent models that are pressure resistant (12). *Note*: The temporary pacemakers are unsafe under pressure but may be safely used in an exterior position with the leads glanded through the bulkhead of the monoplace system.

d. 1970s in the United States, a patient tray made of fiberglass burst into flames on two separate occasions outside of the chamber due to a break in the electrical conducting wires running in the matrix of the material. No patient or attendants were injured (13). The fiberglass trays were replaced by the manufacturer with conductive metal trays.

e. 1970s in Japan, a patient was incinerated in a prototype monoplace chamber. No further development of this particular configuration has occurred to date.

f. 1980s in Italy, a patient was incinerated in a monoplace chamber (14) when the attendant allowed a sparking toy inside. The use of mono-

place chambers was banned by the Italian government.

g. Four monoplace chamber fires have occurred in Japan due to the introduction of lighted butane or chemical catalytic hand warmers into the chamber. The most recent (February 1996) resulted in the rupture of the chamber, because of an excessive fuel load in the form of two synthetic blankets.

h. Seven monoplace fires have occurred in China from 1967 through 1996 resulting in eight deaths.

i. A dramatic fire occurred in Russia when an operator left the patient and mother alone. When the fire occurred, the mother was unable to remove the patient from the chamber.

7. Several design features to improve patient safety in monoplace chambers were added in the 1970s:

a. The development of the flanged O-ring resolved explosive decompression from O-ring failure.

b. Respirator-dependent patients supported with external mechanical ventilators.

c. Maintenance of intravenous fluids and medications (*see* chapter VI).

d. Successful cardiac pacing with external pacing device on the exterior of the chamber.

e. Hyperthermia/hypothermia of the internal environment resolved by passing gases through a heat exchanger and having an adjustable flow rate.

f. Back bleeding from disruption of intravascular lines prevented by check-valves in the intravenous circuit.

g. Control of chest tube drainage with non-return system by use of Heimlich valves.

h. Blood chemistries and tissue gas determinations became available at pressure.

i. Adjustable flow rates for the treatment gases solved the problem of hypothermia in susceptible children by decreasing the flow. The flow rate may be increased, increasing the evaporative heat loss and cooling the patient.

8. Design features created in the 1980s to improve care and safety of monoplace patients (*see* chapter VI for details and references):

a. Noninvasive automated blood pressure device created.

b. Methods of suction in the monoplace chamber.

c. Recognition of limitations of monoplace mechanical ventilators.

d. Methods of withdrawing and determining blood gases.

9. Personal communications with the manufacturers of monoplace chambers would indicate that approximately 5,000 are in service around the world at this time. The USSR having the most, nationally.

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READER'S NOTES

CHAPTER II: CONFIGURATIONS AND ADAPTATIONS OF THE MONOPLACE CHAMBER

George B. Hart, M.D.

Configurations

1. The patient container may be equipped with or without bilges (wet or dry) and must be fabricated as specified by the ANSI/ASME PVHO Code.

2. *In the sphere, spheroid, or cylinder-on-end,* the patient is treated in the seated position. Patient access is usually through a clam shell, hinged, or sliding door opening.

3. In the horizontal cylinder, the patient is treated in the lying position. Patient access is usually through an opened hinged end plate. This model has been the more popular geometric form.

4. The patient is treated in a partial seated or Fowler's lying position in the *sphere and cylinder combination.* Patient access is through a cantilevered horizontal clam shell orifice. This is popular in areas where there is limited space.

5. *Rigid and noncollapsible* chambers are designed to be durable and may have weight of sufficient magnitude to require reinforcement of underlying building supports. They may withstand exceptional pressures, such as 165 feet of sea water or greater. The prevalent models for hospitals have a maximum operating pressure of 3 atm abs. The 3 atm abs pressures were elected for hospital applications to preclude the use of oxygen under greater pressures and thereby minimize oxygen toxicity. *Note*: Fiberglass construction is not permitted because the bonding epoxy compounds deteriorate with time into highly combustible compounds.

   a. Metal hull, metal end plates, and portholes of glass or acrylic.
   b. Acrylic hull, metal end plates.

6. *Collapsible chambers* are primarily used to support diving activities or to transport patients to a treatment facility. They are light weight and with a patient under pressure can usually be moved by four men. Entrance is usually through the cephalic end of the chamber.

   a. Metal collapsing hull with a porthole at the cephalic end plate, the so-called collapsing "tea cup" design.
   b. Nonmetallic, reinforced plastics with acrylic or glass portholes maintained with metallic O-clamps. Models are available for entry through a zippered opening along the longitudinal axis.
   c. Combination of metal and nonmetallic, nonrigid, reinforced plastics. Designed so that head and torso are resting in the rigid portion of the chamber while the lower limbs extend into the collapsible portion.

7. *Fixed configuration* is the favored configuration of those models that require additional structural support due to the intrinsic weight of the chamber or supporting equipment.

8. *Mobile configurations* offer two types of chambers, the wheel mounted and the skid mounted. The wheeled-type is primarily used by hospitals.

9. The patient seat or tray should be configured to maintain proper grounding during treatments while the patient is resting. If the preceding is not possible, a grounding strap will be applied to the patient and attached to the grounding system.

10. *Heat exchangers* are recommended in line to heat or cool the gases entering the chamber for patient comfort and to avoid hypothermia or hyperthermia in the unconscious patient. The gas may require humidification in extremely dry areas to ensure patient grounding and to suppress static discharges.

11. Oxygen is generally used to compress the patient in the hospital setting. However, multiple gases are favored with oxygen as the primary treatment gas, with air available for O_2 seizures and/or air breaks. Having both air and O_2 available permits the option of compressing the patient with air who may then breathe O_2 by mask, hood, or endotracheal tube.

12. The purge rate of monoplace chambers is usually delivered with a minimum flow rate of 200 liters/min and many have no mechanism by which the flow can be increased or decreased. Certain manufacturers may, *upon request,* modify chambers so that the flow rates can be significantly reduced/increased to avoid therapeutic misadventures. *Example*: A child with a large burn and placed in a chamber with the O_2

at 70°F flowing at 200 liter/min may have an unacceptable evaporative heat loss, making the child hypothermic.

13. It is possible to recycle gas with subtraction and/or addition. This method is favored in areas where the costs of the gases are of concern. The present models have some degree of purging, i.e., there is not complete recycling. The favored type in most of the United States is the non-recycled variety as the costs of liquid oxygen and liquid nitrogen are below that of maintaining a recycling unit.

14. All exhausted gases should be vented to the exterior of the building and clear of all neighboring hazards, prevented from possible reentry into the building, and protected by a grille or fence at least 2 feet from the exhaust port.

15. Usual working gas is from a cryogenic supply evaporated to 68°F. Gas is transported by insulated piping.

16. A heat exchanger with the capacity to heat or cool is necessary. A simple radiator design with hot and cold water and a thermistor to actuate below 66°F and above 72°F is adequate.

17. Multiple gases ideally should be available. The air source is configured to avoid hydrocarbon contamination. Filters with a one-micron porosity are placed in line to prevent occlusion of some monoplace mechanisms with calcite crystals from aqueous lubricants commonly used in Teflon compressors.

18. Compressed gas is the emergency supply. The system reacts to loss of line pressure in the cryogenic system, automatically switching to the compressed gas. *Note*: Expanding compressed gas may enter the chamber at a very low temperature and may need to be heated.

19. Communication by two-way microphone-speaker system is mandatory to the safe operation of a hyperbaric chamber, and the system used must be intrinsically safe electrically.

20. The lighting for monoplace chambers should be mounted outside of the chamber and conducted into the chamber by ports, acrylic hull, or fiber optic cable. The illuminating device will not be a source of heat within the chamber.

[*Editors' note*: A comprehensive presentation of monitoring and life-support techniques appears in chapter VI.]

Noninvasive Monitoring

1. *Arterial blood pressure* measurement may be manually operated, either stethoscope operator-dependent equipment or an automated operator-independent device.

2. *Electrocardiography (ECG), Holter, ventilation rate, electroencephalography (EEG), and passive electromyography (EMG)* are available as adapted through glanded pass-throughs.

3. *Laser Doppler blood flow meters* can be used to measure the blood flow of the underlying tissues. Presently they are available, and the fiber optic probes are easily passed through an aperture with an O-ring seal.

4. *Temperature probes* can measure the environment, and topical cutaneous temperature by thermistor is available.

5. Efferent and afferent gas measurement with mass spectrometry or gas chromatography is available.

6. Tidal volume is measured using a respirometer in line with a respirator. *Airway pressure* is monitored with a manometer located inside the chamber.

7. Transcutaneous gas measurement is capable of being performed when the transducer is intrinsically safe in the rated pressure and gas composition of the chamber.

Invasive Monitoring

1. *Arterial and venous blood pressure* transducers must be referenced (i.e., the machine side of the recording diaphragm is at the chamber pressure) to the atmosphere from which it transmits the pressure, or the transducer is in a solid state configuration and unaffected by external pressure. Wedge pressures may be obtained by one of two methods:

   a. The balloon may be wedged with saline and is usually performed before placement of patient in the chamber; this is hazardous as there may be erosion of the involved vessel from the constant pounding on a relatively incompressible obturator.

   b. Inflation of the balloon with a gas is done with the patient at pressure with immediate deflation following the pressure reading; this is the recommended procedure.

2. *Cardiac output* is usually obtained by thermodilution technique and requires a certain amount of muscular effort to inject. A high pressure injector may be helpful but not absolutely necessary (*see* chapter VI for a detailed description of pulmonary artery catheter use).

3. *Rectal or esophageal temperature* thermistor probes are placed in position before the patient is placed into the chamber and properly glanded through

the bulkhead.

4. Blood chemistries and gas analysis may be obtained through properly placed arterial and venous catheters. The check valves in the vascular excess ports must be removed to perform these functions.

5. Mass spectroscopy probes must be placed in the tissues to be studied. The connecting cannulae is passed through a bulkhead orifice and sealed with an O-ring seal to the mass spectrometer.

Life Support Equipment

1. *Respirator*-dependent patients may be ventilated by a variety of pressure-dependent and/or volume-dependent equipment. A respirometer must be in line to monitor the tidal volume. The respirometer must be constantly checked during compression and decompression to ensure proper operation. The ventilators may have the capacity for positive end-expiratory pressure and humidification of the inspired gases, if desired.

2. *External pacemaker leads* are glanded through the bulkhead and must not be placed in the chamber with the patient, because the majority are not designed for operation in an oxygen-enriched environment.

3. *Positive pressure pumps* are employed to deliver intravenous fluids and/or medications to patients in the monoplace chamber. The models presently available are designed for use with the monoplace chamber and may even be used effectively in the fluid resuscitation of patients with large thermal burns.

4. *Subambient pressure* is a result of the differential pressure through the pressure boundary and is usually applied where suction is a requirement, such as a hemopneumothorax deserving of a negative pleural pressure to maintain proper cardiopulmonary functions. This vacuum effect may also be obtained by careful venting, using a needle valve on the outside (*see* chapter VI).

Therapeutic Modifications

1. Gases used to ventilate a patient can differ from the chamber atmosphere through the use of scuba regulators, masks, closed-circuit devices (when intubated), or hoods. This allows the use of "air breaks" or blended gases.

2. *Chemotherapeutic agents* may be delivered at time of treatment by positive displacement pumps when the target cells and/or organisms are radiosensitized.

3. Radiation sources may be positioned externally to ports or translucent hulls to irradiate tumors. However, the effects of ionizing radiation on acrylic plastic may be of concern in long-term use.

Patient Resting Device (Chair or Tray)

1. *Fixed* (i.e., remains within the chamber at all times). These are engineered to be electrically safe within the environment in which they are placed. The chair may be adjustable to reclining or it may be in a fixed, upright position.

2. The patient must be placed on this *tray* at the chamber site as it is not detachable in the usual sense for use as a transport device. The device may be capable of raising or lowering the head of the patient. *Mobile trays* (i.e., easily detached from the chamber and may be used to transport the patient from one point in the health care facility to another) are engineered to become electrically safe by contact points placed in such a position that the device is grounded when positioned for treatment within the chamber. An alternative to the aforementioned is separate grounding of the patient by a grounding lead or probe when the tray or chair cannot be grounded. The mobile tray is usually transported on top of a wheeled lower portion, utilizing the combined arrangement as a hospital gurney. The tray easily detaches and slides from the wheeled portion into the chamber. Special trays may be acquired for cervical traction, x-rays, or magnetic resonance studies. *Note*: These trays have special grounding requirements as they are fabricated from nonconductive materials and the patient must be separately grounded. The wheeled chair type may be adjustable to a reclining position or in a fixed, upright mode.

3. No item should be inserted into the chamber that is not intrinsically safe for the rated pressure of the chamber used.

4. *Mattresses or chair cushions* are covered with conductive material which lie on conductive contacts, thereby ensuring electrical stability of the patient within the chamber. If the mattresses/cushions are not so covered or if no conductive contacts are provided, the patient should be separately grounded.

5. A television placed within the patient's visual field and the accompanying sound piped into the interior of the chamber will entertain the patient during the treatment. Music and biofeedback sounds can also allay anxieties and help pass time during the treatment periods.

6. Wide-angle mirrors appropriately placed so that the patient and chamber operator may have continual visual contact is soothing to the patient.

Emergency Configuration

1. *An alternate gas supply should be available.* This is usually solved by a battery of large oxygen cylinders arranged in cascade to continue necessary treatments.

2. *An alternate electrical supply should be available.* This is a requirement of all health care facilities and if the chamber is used for therapeutic reasons they should comply.

3. *Emergent extraction of the patient.* A capability will be available so that the patient may be exited from the chamber within 90 s. This is most important in evacuating the patient from either internal or external calamity.

4. *Fire suppression devices.* A redundancy of fire suppression devices is recommended for the immediate vicinity of a monoplace chamber such as:
   a. sprinkler system,
   b. CO_2 extinguisher,
   c. chemical extinguisher, and
   d. high pressure water hose.

CHAPTER III: REGULATIONS FOR MONOPLACE CHAMBERS

Dick Clarke

Introduction

1. The monoplace hyperbaric chamber is designed to allow the entire body of a patient to be exposed to a specific gaseous environment under an increased atmospheric pressure. The monoplace hyperbaric chamber has been designated by the National Fire Protection Agency (NFPA) as a Class B Chamber because it is rated for single human occupancy. Techniques of use differ significantly between the monoplace (Class B) chamber and the multiplace (Class A) chamber because of occupancy, the atmosphere, and the pressure.

2. Monoplace chambers do not require major alterations of a health care facility to become operational, but in all cases it is recommended that the following safety standards be met.

Hyperbaric Chamber Facility

1. When a health care facility elects to install a monoplace hyperbaric oxygen (HBO_2) treatment cham-ber there are several considerations necessary for safe and efficient operations. The minimum considerations are specified within the National Fire Protection Association Standards for Health Care Facilities (NFPA 99), Chapter 19.

2. The room in which the chamber is to be housed should be dedicated exclusively to the hyperbaric operations.

3. The ideal location for the chamber is in a room with at least one outside wall. This reduces the total length of pipe required to exhaust the oxygen from the chamber and takes advantage of natural illumination. Additionally, it should be accessible for outpatient traffic.

4. The physical size of the chamber room depends on the number of chambers to be installed. If only one chamber is to be located in the room, the minimum size of the room should be 10 feet wide by 22 feet long. If a second chamber is to be located in the room, it should be at least twice as wide. The major reason for the increase is to accommodate the movement and storage of each gurney independently within the chamber room. Space consideration must be made for the operator and the orientation of the chamber control panel.

5. If each chamber has an operator, the chambers may be placed in parallel facing the same direction. In most cases one operator will manage both chambers. This requires the controls of both chambers to be within sight and reach of the operator at all times. To satisfy this requirement, the chambers must be placed in opposite directions or have reverse control panels. Space should be primarily allocated for the chamber, transfer dolly patient monitoring, life-support equipment (i.e., ventilator, suctioning equipment), ancillary support equipment, desk, and file cabinet for records.

6. The chamber room should have adequate space for emergency procedures in the event of cardiac arrest and/or seizures. For chambers compressed with 100% oxygen, any procedure requiring electrical equipment (i.e., defibrillation) must be accomplished at least 6–8 feet from the open door of the recently decompressed chamber. It is recommended that the chamber facility have a room for patients' changing and rest room accommodations. Additionally, needs for equipment storage, gas cylinders storage, linen storage, administrative space, wound care, and medical supplies should be provided. The chamber room should be well lit. The best artificial lights are incandescent lights. Fluorescent bulbs emit red ultraviolet light which will eventually cause deterioration of the acrylic chamber shell. Direct sunlight on the acrylic chamber shell will also cause crazing which is the early sign of acrylic deterioration.

7. In most cases, rooms within a health care facility are equipped with a wet-pipe overhead, fusible-link sprinkler system. It is recommended that in addition to the overhead sprinkler system at least two portable fire extinguishers be strategically located in the room.

8. Class A fire extinguishers contain a water-based extinguishing agent and are used in fires involving rubber, plastic, wool, linen, and paper.

9. Class B fires involve flammable liquids and class C fires involve electrical equipment. The ABC type fire extinguishers are dry chemical units which can be used on all three types of fires.

10. The dry chemical extinguishers, if used, leave a powdery residue which must be cleaned up. The Halon extinguisher, when used on a fire, dissipates the oxygen and smothers the fire. Because of the toxic by-products associated with Halon, the room must be ventilated immediately after use. The ABC type fire extinguishers are the recommended type.

11. In addition to fire extinguishers in the room, "No Smoking" signs must be displayed in open view, and the operators must enforce a no smoking policy.

12. Because the operator may not leave the patient while the chamber is pressurized, it is recommended that a telephone for emergency use be installed near the chamber. In the event of a fire, the chamber operator must be able to signal or call for assistance without leaving the patient. The room must be equipped with an emergency lighting system that will automatically activate in the event of a complete power failure. This is necessary to continue operation of the chamber system as well as for the safety and assurance of the patient. A battery-operated communications system or a sound-powered telephone is necessary to maintain a communication link between the operator and the patient. Similarly, an emergency summons button ("code alarm") is useful to summon appropriate individuals in case of a medical emergency.

13. To eliminate static electricity and to maintain cleanliness of the chamber room, conductive tile, concrete, or terrazzo is recommended.

14. The temperature in the room should ideally be maintained near 80°F and the humidity within the chamber room must be maintained above 50% relative humidity. This humidity control is necessary to eliminate the static electricity charge buildup in the room and within the chamber.

15. There are no special requirements for furniture in the hyperbaric chamber area; however, care should be taken when cleaning or waxing furniture so that compounds do not come in contact with the chamber.

16. It is absolutely essential that the chamber room and all equipment be kept clean and free of grease, oils, dirt, dust, and lint. A regular housekeeping program must be implemented and maintained even during periods of inactivity of the chamber.

17. The surface of conductive floors must not be insulated by a film of oil or wax. Any waxes, polishes, or dressing used for maintenance must not adversely affect the conductivity of the floor.

Hyperbaric Treatment Chamber

1. A monoplace hyperbaric treatment chamber primarily consists of the pressure vessel, a protective cover for the pressure vessel, a pressure control system, a communications system, penetrators for patient monitoring and life support, and the appropriate safety systems.

2. The approved monoplace treatment chamber is one that has been designed, fabricated, and tested to meet the safety standards for human occupancy as specified by the American Society of Mechanical Engineers (ASME). The standard specifies that the materials approved for use in the fabrication of the pressure vessel, the necessary design codes, design calculation, quality control, the inspections and tests for certification, final code stamping, and final reports must be retained by the manufacturers for a period of 5 yr. The owner should retain a copy of all certification records for insurance purposes and for a resale. Chambers meeting all of the stringent specifications for human occupancy will carry the appropriate approval by ASME-Pressure Vessels for Human Occupancy (PVHO-1) or Lloyds of London.

3. Although there are several different models of monoplace chambers available on today's market, they all are similar. The current approved models are manufactured of a clear acrylic cylinder which is designed and tested to safely hold a pressure of several times greater than that of the nominal operating pressure.

4. In the Sechrist (Sechrist, Inc, Anaheim, CA) and Vickers (available through HYOX, Westhill, Aberdeen, Scotland) monoplace chamber design, the acrylic pressure vessel is protected by the installation of a second clear acrylic cylinder. This cylinder is installed over the primary pressure vessel to protect the pressure vessel from external impacts and/or scratches. The outer cylinder contains pressure-relief holes designed so that if the inner pressure vessel fractures, the void space between the acrylic tubes may act as a small volume tank and will bleed down the escaping gas at a slow and even rate back to surface pressure.

5. The Perry Sigma I (Perry Baromedical Services, Riviera Beach, FL) and the Nautilus monoplace chamber (no longer available) employ only a single pressure vessel with a thin sheet of acrylic wrapped to protect against scratching. Because there is only one tube, the pressure vessel is designed and constructed using a thicker acrylic tube than that of the Sechrist or Vickers chambers.

6. The acrylic cylinders of the aforementioned designs are supported at either end by metal end bells which are connected by four (or five) equally spaced tie rods. These tie rods provide the pressure-sealing

adjustments on the acrylic cylinders.

7. Tightening or loosening of individual tie rods will cause out-of-adjustment problems and will result in major leaks at the end seals.

8. The door of the chamber contains a pressure-sealing O-ring or gasket assembly. This O-ring or gasket is a critical element in the normal pressure-sealing operation of the chamber, and great care should be taken to protect it from damage, dirt, or dryness. Because the O-ring or gasket is located at the door end of the chamber, the stretcher or bed may accidentally damage the O-ring during loading or unloading of the patient.

9. The door gaskets of the Sechrist and Nautilus chambers are a special design and, once damaged, will leak when the door is closed. The gasket should be replaced before further operation.

10. It is wise to have on hand a spare door gasket, which is easily replaced. When replacing the door gasket, apply to this gasket a light coat of halocarbon or other oxygen-approved lubricant. While the gasket is out, clean the gasket or O-ring groove thoroughly.

11. The Vickers chamber has an O-ring in the door and must also be replaced when damaged. If the O-ring is damaged causing a minor leak, and a spare O-ring is not immediately available, remove the O-ring, clean the groove in the door, and turn the O-ring over so that the damaged area in the O-ring faces into the O-ring groove. This will provide an emergency stop gap until a new O-ring can be obtained. Again, it is wise to have a spare O-ring on hand.

12. Other monoplace chambers are presently being used for human occupancy but have not been approved for use by ASME. Some of these chambers are designed and fabricated using a molded fiberglass assembly. This molded fiberglass has been identified as having serious delamination problems and could fracture violently. The second inherent problem is that when fiberglass is drilled, cut, or fractured it splinters, causing airborne particles which could be breathed by the patient.

13. As required by the ASME, each treatment chamber is equipped with at least one pressure relief valve. The pressure relief valve is maintained closed by spring tension. This spring tension will be overcome by the pressure within the chamber exceeding the design or working pressure of the chamber. This pressure setting is usually 10% over the operating pressure rating of the chamber.

Chamber Penetrators

1. On the acrylic-type chamber, the penetrators for all electrical connections, ports for intravenous infusions, ventilators, etc., are located in the metallic end bells or the door. No penetration, unless installed by the manufacturer, is allowed. Alterations of any sort are not permitted in the chamber pressure vessel, neither in the acrylic nor in the metal end bells.

2. When an intravenous infusion is required during a treatment, the utilization of a positive pressure displacement pump is required. It is also mandatory that a check valve such as an Abbott Lab model 1850 back-check veno-tube or Cobe Hyperbaric back-check valve (Cobe Inc, Lakewood, CO) be installed inside the chamber to prevent injury to the patient in the event of severing of the outside i.v. tubing.

Electrical Systems

1. The design analysis covering all hyperbaric and support electrical systems should be made in accordance with design procedures. Methods used in determining conductor sizing, protective covering, protective devices, and other equipment needed to complete a good, safe hyperbaric electrical system are required. Electrical system designs are governed by using existing location and national electrical codes. The National Electric Safety Codes augmented by the National Fire Protection Association Codes, NFPA, 70 NFPA 99, should be strictly followed.

2. All essential electrical equipment and circuits associated with the hyperbaric system should have a minimum of two independent sources of electric power.

3. The chamber electrical system must be wired to the health care facility emergency electrical power system.

4. All electric power being supplied to the hyperbaric treatment chamber, as well as all ancillary equipment supporting the chamber or connected to the patient in the chamber, must be fed from a ground fault interrupter (GFI) equipped with a line-isolating transformer system with appropriate indicating lamps. It is desirable that this indicator be capable of sensing single or balanced capacitive-resistive faults, as well as leakage of current to the ground.

5. An example of a ground fault interrupter system (Fig. 1), which has been certified and approved for use in and around hyperbaric systems, is the Daniel Woodhead model 1670.

6. The primary line of the GFI is plugged into a standard 120-V wall receptacle, and since the line

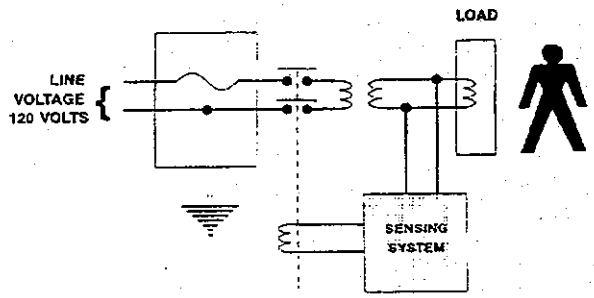


Fig. 1—Ground fault interrupter system.

isolating transformer ratio is 1 to 1, the secondary provides 120 V at the convenience outlets. However, since the transformer is an inductive link rather than a direct connection, there is no complete path for the fault current to flow back to the source.

7. The sensing system is incorporated into the secondary circuit of the transformer. This sensing system continually monitors the output of the ground fault interrupter and instantaneously detects when the fault current exceeds the rated trip current of 0.75 mA. When excessive fault current is detected, the sensing circuit opens both sides of the primary power within 15 ms. The full load rating of the GFI should be rated twice the current requirements of the equipment to be used. Each ungrounded circuit within the hyperbaric system should be controlled by a switch outside the pressure vessel having a disconnect pole for each conductor. These poles should be ganged.

8. Any switch, receptacle, contactor, and attachment plug not designed for use in hyperbaric systems are prohibited because of the spark or arc that may occur in their normal use.

9. Special magnetic switches, if designed to work with hyperbaric applications, are acceptable. If a switch is required within the chamber, a magnetic contact is provided inside and the electrical elements are outside. Closing the magnetic contact will pull in the electrical coil and activate the relay.

10. All circuits and equipment installed within the chamber must be intrinsically safe. The fundamental side of intrinsic safety is to limit the energy which circuits or systems can draw from a power supply, even under faulty conditions, to levels incapable of causing ignition in a hyperbaric or hazardous environment.

11. All wiring within the chamber must terminate on a terminal board and must be hard wired or soldered. Wires carrying low signal voltage and low current levels may be installed in removable connectors of the screw type to prevent accidental parting or arcing.

12. All wiring in the chambers must be routed within a protected cover or a metallic conduit. Cable insulation installed in the chamber must be nontoxic and nonflammable in oxygen-enriched environments. Internal wiring must be high temperature, Teflon-coated, and flame-resistant and must comply with MIL-W-16976D. All chamber lighting systems must have the heat and electrical elements outside of the pressure vessel.

13. Grounding of the system is very important. Each chamber shell must be connected by a no. 6 AWG braided copper cable to earth ground. This ground is separate from the building power supply or other equipment grounds. All electrical and metallic equipment in the chamber must be connected by ground cables to the chamber. The bunk also must be grounded to the chamber.

Chamber Communications (and Entertainment)

1. All components of the communications systems, microphones, speakers, and hand phones or headsets, should be approved intrinsically safe. The system should have an output voltage level of less than 5 V. All audio amplifiers, transformers, or power segments of the communication system are located outside the chamber.

2. Entertainment systems, such as radios and television, unless designed for use within hyperbaric environments, are located outside the chamber. Electrical power for television and radio must be through the ground fault interrupter.

3. All patient monitoring equipment, unless modified or designed for chamber use, should be located outside of the chamber and the monitoring leads routed through an approved electrical connector. The termination must be soldered, or an approved connector with a threaded outer shell that makes positive connection and cannot be accidentally pulled out by the patient must be used.

4. A typical example of a communication system is one installed in the Sechrist chamber which consists of an intercom assembly mounted at the chamber control panel, a chamber-mounted battery pack, and a wall-socket-mounted, Underwriter's Laboratory (UL)-approved battery charger with cable and jack plug. The charger assembly produces 14.3 VDC.

Static Electricity

1. In addition to the normal safety precautions of electrical voltage being routed into the chamber, the system must be equipped to safeguard against the

generated electrostatic sparks within the chamber itself.

2. The patient, who by normal movements within the chamber generates electrostatic electricity, must be grounded to a metallic part of the chamber.

READER'S NOTES

CHAPTER IV: THE MONOPLACE HYPERBARIC CHAMBER FACILITY

Judy Johnson

Physical Requirements

1. A monoplace chamber may be placed in almost any area of a hospital. However, the room housing the chamber must be designated exclusively for hyperbaric medicine. No other diagnostic or therapeutic procedures should be performed in this room. While a ground-floor location with an outside wall is not necessary for safety purposes, logistically it is highly desirable.

2. The size of the hyperbaric unit must be sufficient not only for the physical requirements of the chamber, transfer dolly, ventilator, and ancillary support equipment, but must also be adequate to handle emergency procedures necessary in the event of cardiac arrest and/or seizures, etc. For chambers compressed with 100% oxygen, any electrical procedures performed on the patient (i.e., defibrillation) should be accomplished at least 6–8 feet from the open door of the recently decompressed chamber. Therefore, the length and width of the chamber room must be able to accommodate this extra space. Additionally, emergency evacuation procedures should be taken into consideration when determining room size. The ability to mate the dolly to the chamber and extricate a patient should be maintained. (*Example*: Do not place two chambers at an angle such that only one chamber can be unloaded at a time.) Adequate space to function smoothly with acute patients is also an important consideration.

3. The physical orientation of the chamber within the room should be determined according to the requirements of ingress and egress for ease of patient transport, as well as emergency evacuation design.

4. There are no special requirements for furniture for a room housing a monoplace hyperbaric chamber. However, care should be taken when cleaning or waxing furniture that compounds do not get on the acrylic cylinder or inside the chamber.

5. Flooring in the chamber room must be a hard surface such as tile, linoleum, or concrete. Conductive flooring material is not required for a monoplace chamber facility. No carpeting or surfaces lending themselves to a buildup of static electricity should be used in the room.

6. While windows provide a psychological advantage to the patient by extending their field of vision, direct sunlight on the chamber can cause damage to the acrylic material. Be sure that some type of window covering can be employed during times of the day when the sun may shine directly on the chamber.

Engineering Requirements

1. The temperature in the room should be maintained for the comfort of the patient during the setup of the treatment and for personnel operating the equipment. Humidity should be maintained at 50–60% to minimize the buildup of static electricity.

2. The type and placement of lighting in the baromedical unit is very important. Fluorescent lighting should not be used during the hyperbaric oxygen therapy treatment. Flickering from the tubes may cause medical problems for the acute or unstable patient. If fluorescent lights are left in the room, a strict protocol of turning them out during actual pressurization is necessary. Incandescent lighting is acceptable but should be equipped with a rheostat. No light should be placed directly above the patient's eyes.

3. A solid earth grounding system must be provided for the chamber. The system must terminate in the room with a 3/8-inch (1 cm) no. 16 United National Coarse (UNC) stud. The earth grounding system must conform to local electrical codes as a minimum. All other electrical equipment in the hyperbaric facility must be properly grounded and in optimum working condition.

4. Electrical service with a standard 110–115 V, 60-cycle wall socket must be provided.

5. Electrical monitoring of various patient parameters can be accomplished while the patient is under-

going hyperbaric therapy. The correct interfacing of monitoring equipment with the monoplace hyperbaric chamber is critical. Pressure-fitted electrical connectors and patient cables are provided with the hyperbaric chamber. All electrical monitoring must be accomplished through these connectors. All electrical devices must be on the outside of the chamber with wiring to electrodes and transducers inside the chamber properly shielded and isolated. Transducers for blood pressure signals must be properly vented to prevent pressure buildup and destruction of the device during pressurization. Before purchase or adaptation of monitoring equipment, contact the chamber manufacturer for recommendations regarding safety and compatibility.

6. The monoplace chamber's intercommunications system consists of an intercom assembly mounted at the chamber control panel, a chamber-mounted battery pack, and a wall-socket-mounted battery charger with cable and jack plug. Chamber charger assemblies are an Underwriter's Laboratory (UL) recognized power supply. The charger assembly produces 14.3 V of direct current (VDC). All auxiliary audiovisual equipment must input into this charger power supply. No other wiring of the chamber for audiovisual equipment is acceptable.

7. The chamber facility must have an emergency call intercom system available in close proximity to the chamber. This system should allow for calling a "code" situation as well as providing a communication link to other hospital personnel.

Fire Safety

1. Room construction should meet the requirements of local codes that govern housing of Class "B" hyperbaric chambers. Construction to National Fire Protection Association (NFPA) Code 99 specification is recommended. NFPA Code 99 exempts Class "B" chamber facilities from 2-h rated walls and 1.5-h rated doors.

2. Preventing a fire in a monoplace hyperbaric chamber or facility is the number one priority to be accomplished. "No Smoking" signs are to be prominently displayed on the walls outside the room and inside the facility. Two standard fire extinguishers should be installed in each chamber location. Static electricity should be kept to a minimum. All previous discussions relating to the grounding, safe use, care, and maintenance of the chamber and all ancillary equipment in the hyperbaric facility pertain to this fire prevention issue. Preventive measures relating to the patients will be addressed in a subsequent chapter. A strict fire safety and prevention policy should be written and adhered to in all hyperbaric facilities.

3. An emergency evacuation plan should be designed to cover a chamber-involved fire or a fire in or adjacent to the room. Fire drills should be ongoing events designed to provide optimum functioning during an emergency. Should a chamber fire occur, all personnel should evacuate the room immediately (turning off the oxygen zone valve outside the room). If there is more than one chamber in the room, the patient in the uninvolved chamber should be evacuated by emergency-venting the chamber. If a room fire or a fire in the near vicinity occurs, the oxygen valve in the room controlling the chamber(s) should be turned off and all patients evacuated as soon as it is safely possible.

CHAPTER V: GAS SUPPLY AND EXHAUST SYSTEMS

Jim McCarthy, P.E.

Introduction

1. Several important aspects of the oxygen supply system support the overall operation of the hyperbaric treatment chamber. The purity of the gas, sufficient pressure and flow to support the operation of the chamber and auxiliary equipments, the system cleanliness, and finally, the overall system safety.

Purity Standards—Oxygen

1. Oxygen is normally supplied from a liquid (cryogenic) system. Liquid O_2 has a much greater capacity to support combustion than has air. Liquid O_2 should not be kept in confined or poorly ventilated areas because potentially hazardous concentrations of O_2 gas may collect temporarily due to vaporization and venting from containers. Piping should be well insulated, and appropriate danger signs posted.

2. Porous organic materials, such as clothing or wood, may retain O_2 for a considerable period of time. Mixtures of organic materials, petroleum products, asphalt tile, and liquid O_2 should not be kept in confined or poorly ventilated areas because of the reasons stated above. Liquid O_2 containers should never be installed on or over asphalt pavement or asphalt tiles; and when stored outside, all grasses, weeds, and shrubbery should be kept cleared at least 10 feet around the storage area. The area in and around the O_2 storage vessels should be constructed of concrete, or at least have a gravel foundation. The O_2 storage should have a chain link fence at least 6-feet tall installed around the area. Piping should be well insulated and appropriate "Danger" and "No Smoking" signs posted.

3. Oxygen is also stored for auxiliary purposes in the hospital and in some cases even plumbed into the hyperbaric system as emergency backup to the main supply.

4. Oxygen in the gaseous form is produced in different purities to support medical purposes as well as industrial applications. Care should be taken to use only bottles marked "Oxygen U.S.P." or "Aviators" grade and refrain from using bottles marked "oxygen." When gaseous O_2 is ordered, it must be at least grade E (99.5% pure). When the O_2 is delivered, the quality certification papers should be obtained. The accepted purity standard for gaseous O_2 is taken from the U.S. Navy and shown in Table 1. All O_2 sources should be checked for purity before placing on line for clinical use. This may be done by using a portable O_2 analyzer and flowing O_2 over the sensing cell (Table 1).

Volumetric Requirements

1. There are three initial volumetric considerations when installing and/or operating a monoplace chamber system:

   a. The volume of O_2 required to pressurize the chamber, the rate of compression, and the volume required to ventilate the chamber throughout the entire treatment.
   b. The facility O_2 supply system must be of sufficient size to support the total chamber gas requirements (liquid-to-gas ratio: 1 cubic foot of liquid O_2 at its normal boiling point is equivalent to 860.6 cubic feet of gaseous O_2 at standard temperature and pressure–STPD).
   c. The piping in the facility must be sized sufficiently to support the chamber volumetric and flow requirements without affecting the other hospital requirements.

2. Each monoplace chamber has a specific volumetric and flow requirement. This basically is determined by the size of the chamber, the rate in which the chamber is compressed, and the flow requirements for both ventilation and to support patient comfort.

3. The Sechrist chamber has a floodable volume of 25.4 cubic feet (726.9 liters) and requires a total of 50.8 cubic feet (1,454 liters) to compress to 3 atm abs. The ventilation requirements vary from a minimum of 240 liters/min to a maximum of 450 liters/min (STPD) compounded by the length of the treatments; either 60

Table 1: Purity Standard for Gaseous Oxygen

Constituent	Type 2
Carbon dioxide (CO_2)	5
Methane (CH_4)	25
Acetylene (C_2H_2)	0.05
Ethylene (C_2H_4)	0.2
Ethane (C_2H_6) and other	3
Halogenated compounds	
Refrigerants (Freon, etc.)	1
Solvents (trichloroethylene, carbon tetrachloride, etc.)	0.1
Other (each discernible from background noise on infrared spectrophotometer)	0.1

or 90 min. Thus, ventilation varies from a low of 508.8 cubic feet (14,407 liters) to a high of 1415.2 cubic feet (40,500 liters) for a typical treatment. This ventilation volume added to the initial pressurization volume brings the low volumetric requirement to 559.6 (15,846 liters) and the high volumetric requirement to 1,466 cubic feet (41,954 liters) per treatment.

4. The Vickers chamber has a floodable volume of 18.4 cubic feet and requires a total of 36.8 cubic feet to compress the chamber to 3 atm abs. The ventilation requirements vary from a low of 240 liters/min to a high of 400 liters/min, and again either a 60- or 90-min treatment time. The ventilation volume added to the compression gas brings the low volume requirements to 545.6 (15,449 liters) and a high of 1,308.5 cubic feet (37,051 liters) per treatment. Other chambers have similar internal volumes and should be calculated to determine the O_2 requirements.

Hospital Piping

1. The facility or hospital O_2 supply may be from a liquid (cryogenic) source common to the entire hospital or dedicated to the hyperbaric facility. Where a dedicated O_2 source is installed, it should be sized to provide a reasonable number of treatments without refilling or changing the tanks. Under normal use and at normal conditions of temperature, a Linde GP 45 cryogenic tank will provide essentially nine treatments when the chamber is at the 240 liter/min ventilation rate on a 60-min table, or six treatments when the chamber is at the 450 liter/min ventilation rate on a 90-min table. For adequate volume as well as for safety backup, at least two GP 45 tanks should be plumbed in parallel and should be operated one at a time, keeping one tank in reserve at all times. The GP 45 tanks can be refilled in place or returned to the supplier for filling.

2. Metals used for liquid O_2 equipment must have satisfactory physical properties at the low operating temperatures. Ordinary carbon steels lose their ductility at liquid O_2 temperatures and are considered too brittle for this service. The most suitable and most commonly selected are copper, austenitic stainless steel, and monel. Piping and manifold systems for O_2 should be constructed only under the supervision of a competent engineer who is thoroughly familiar with the problems incident to the piping of combustible gases.

3. The size of the piping from the hospital O_2 source the chamber is as important as the gas volume requirements. With the flow of 25.4 cubic feet (727 liters) per minute to pressurize the chamber, a supply line of at least ¾ inch (19 mm) is required. However, there are many other considerations when selecting the size of supply line, such as the depletion of other hospital O_2 requirements on the same line.

4. The hospital engineer should be involved in early planning for monoplace installation to ensure that the O_2 requirements are met without interference with other hospital requirements. If the O_2 supply line serving the chamber has other O_2 demands, this volume must be added to the chamber O_2 supply requirements. Additionally, if critical requirements such as surgery O_2 demands are on the supply line, the size of pipe must be calculated.

5. As a second or more chambers are added, consideration should be given to the increased support requirements both in the hyperbaric facility and hospital. The line size may need to be increased to support the additional requirements.

6. Normally, the chamber will require a line pressure of 55–60 psig (3.75–4.1 kg/cm^2), but when ancillary equipment such as the ventilator is added to the chamber system, the line pressure may need to be boosted to 70–75 psig (4.75-5.1 kg/cm^2). This increase in pressure must be coordinated with the hospital engineer. In most cases, a ventilator will be operated from a dedicated O_2 source, such as high pressure bottles, reduced to the required 60–80 psig (4.1–5.45 kg/cm^2).

7. A main supply line safety shut-off valve must be installed adjacent to the hyperbaric treatment room. This valve must be easily and readily accessible to the

chamber operator.

Chamber Supply Piping System

1. The piping of O_2 supply systems for monoplace chambers is specified and governed by National Fire Protection Association, American Society of Mechanical Engineers/Pressure Vessels for Human Occupancy, and the Compressed Gas Association.

2. At a point within the room where the O_2 is supplied, a separate O_2 control panel should be installed. A panel (Fig. 1) should be installed for each chamber. This panel contains a shutoff valve and a pressure gauge. This valve provides the main safety shutoff in the event of a fire and is essential when maintenance and calibration procedures are performed on the chamber. The shutoff valve for most low pressure lines (equal to 125 psig [8.5 kg/cm^2]) should be a ball valve (quarter turn) to eliminate line flow restrictions. If a high pressure source is installed as the primary or a secondary system, a globe valve (multiple turn) must be installed. This will bring the pressure in the line up slowly to avoid adiabatic heating. **Do not install a quick-opening ball valve on a high pressure O_2 system.**

3. A pressure gauge should be installed on the panel downstream of the shutoff valve to provide the operator with visual indication that the O_2 is on line for a pretreatment checkoff and to monitor the O_2 pressure during the entire treatment. The pressure gauge is also utilized during maintenance periods. An O_2 alarm system installed in the line is desirable.

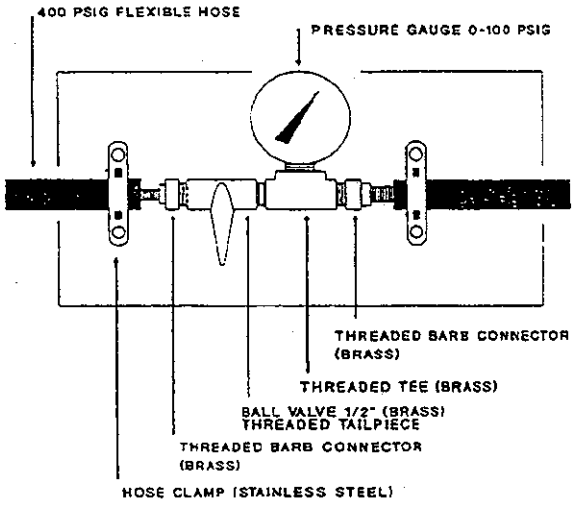


Fig. 1—Pressure gauge configuration.

4. If the chambers are not so equipped, an inline filter is recommended to be installed in the main supply line. This filter removes dirt and construction debris. The dirt in the hospital O_2 line, if not filtered, may eventually flow into critical components of the chamber control system and cause calibration problems and, in some cases, cause the chamber to operate poorly, erratically, or to completely lose operating control. Construction debris such as small shavings of copper, brass, silver solder, and other bits of metal can cause a clogged line or, in worst case, a fire in the line by impact heat.

5. The filter recommended for use in the O_2 system is a 5-micron filter capable of flowing at least 30 cubic feet (858 liters) per minute.

6. The O_2 supply hose from the O_2 panel to the chamber must be constructed of O_2-compatible materials, either a metal-reinforced hose which is internally lined with Teflon, or a nylon-reinforced Tygon hose. The hose must be rated for 400 psig (27.5 kg/cm^2) minimum. The metal-reinforced hose is equipped with positive threaded connectors on each end which mechanically attach to the supply panel and to the chamber. The nylon-reinforced hose may be attached to the panel and the chamber, using stainless hose clamps.

7. It is important that when the hose is connected from the panel to the chamber no undue stress is placed on the panel or the O_2 supply piping, and that no kinks or sharp turns are made in the hose that could cause a flow restriction. The connecting hose must be routed so that it will not cause a trip hazard or be crushed or rolled over.

8. At the completion of the construction or modification of the oxygen piping, a leak check should be made on the joints and components to ensure system integrity. Table 2 provides a list of commercially available leak test solutions. A note of caution: The residue of the test solutions is flammable. All surfaces to which leak test solutions have been applied should be adequately rinsed with water to remove the residue.

Chamber Exhaust Piping System

1. The exhaust line of the monoplace chamber is as essential in the proper operation of the system as the O_2 supply line.

2. The volumetric requirements of the chamber

Table 2: Commerical Leak Test Solutions

Sherlock Leak Detector, type cG
Winston Products Company, Inc.
Charlotte, North Carolina
SNOOP Leak Detector
Nuclear Products, Company
15635 Saranac Road
Cleveland, Ohio 44110
OXEQUIP 17-A Oxyleak
Oxequip Health Industries
8335 S. Halsted Street
Chicago, Illinois 60620
F-3 Detergent
Dow Corning Corporation
Midland, Michigan 48586-0994
LEAK-TEC
American Gas and Chemical, Inc.
New York, New York
Concentrated soap solutions using Joy, Ivory, Tide, Fels-Naphtha, and other similar soap liquids diluted with tap water

dictate the basic size of the exhaust line. Under normal conditions where the chamber is located near an outside wall and the exhaust line is no longer than 15 feet (4.57 m) from the chamber, the size may remain the same size as the chamber exhaust pipe, but where a greater length is required to exhaust, the line must be double in area to eliminate gas flow-back pressure. For example, the cross-sectional area of a 1.5-inch (3.8 cm) exhaust is 1.76 square inches (11.36 cm^2) and a 2-inch (5.1 cm) exhaust line is 3.14 square inches (20.26 cm^2).

3. When a second monoplace chamber is added to the same room, a separate exhaust system is the ideal so that one chamber will not impose any back pressure on the exhaust line of the other chamber. But if it is necessary to couple the chambers, then the exhaust line must be sized to accommodate both exhaust flows.

4. The exhaust piping should be of rigid construction piercing the building wall. The piping may be either of copper or PVC. The pipe must extend into the room at least 3 inches (7.62 cm). The exhaust line outside the building must not run or terminate near any electrical apparatus (air conditioner, electrical panel) and must be out of normal reach. If the exhaust is located on the ground floor, the piping must rise above the ground level at least 8 feet (2.44 m). The end of the pipe must be protected from rain or water entry by installing an elbow turned downward. The best configuration is a tee and two elbows facing downward. This will better ensure no physical blockage of the exhaust line. A screen installed over the end will ensure that nothing will crawl or fly into the end and cause restrictions. The pipe should be secured to the wall to eliminate vibrations and falling. Remember that pure O_2 is flowing out of the end of the pipe and all precautions must be taken to ensure that no person or equipment will ignite the exhausted O_2.

Air Supply System

1. The use of O_2 as a therapeutic agent under pressure in a treatment chamber requires awareness that O_2 poisoning can occur to the patient. Oxygen poisoning is completely reversible. Continued exposure after the early stage of poisoning will prolong the recovery period and will eventually produce irreversible residual effects.

2. When the onset of O_2 poisoning is detected, the procedure is to remove the patient from the high O_2 concentration and return to breathing air. This is normally accomplished by decompressing the chamber and bringing the patient back to a 1 atm air environment. During the decompressing of the chamber, the patient must be closely monitored for normal breathing rates. If a convulsion occurs during decompression, a brief period of breath holding may result in a fatal air embolism.

Chamber Air Supply Piping

1. An alternate solution to the emergency decompression procedure is to provide an air source to the patient. It should be remembered, however, that it takes about 15 min to change the O_2 atmosphere to air. This is accomplished by plumbing the O_2 and hospital grade air directly to the chamber gas selector panel and, as required, the O_2 source closed and the air brought on line. If a parallel O_2 and air system is to be used, the purity of the air must meet the stringent standards of compressed air for human respiration and additionally must meet all safety criteria for O_2 compatibility and cross contamination.

2. The gas and air panel (Fig. 2) should be designated to provide either gas or air only and **not an accidental mixture of the two.** The shutoff valves should be designed with a positive lock or backed up with a check valve in each line.

3. The O_2 supply line and the air supply line should each have a pressure gauge upstream of the shutoff

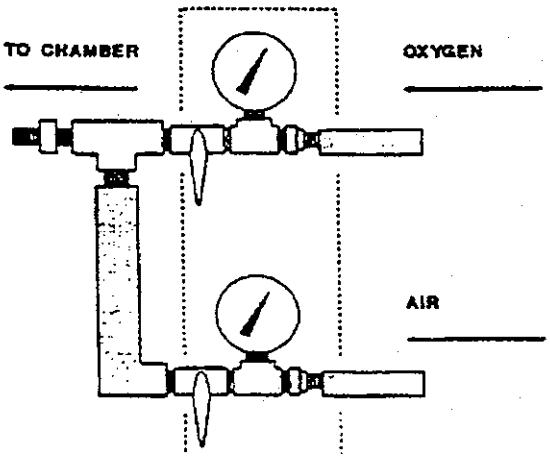


Fig. 2—Mixing configuration.

valve. With these pressure gauges installed, the chamber operator will always know the line pressures for the treatment gases.

4. An inline O_2 analyzer is recommended if a gas other than O_2 is delivered to the chamber.

Purity Standards—Air

1. The purity standard of compressed air for human respiration has emerged from the U.S. Navy Diving Manual, the Medical Gases and Atmospheric Gases Committee Reports, and from the Compressed Gas Association (CGA). The most commonly accepted purity standard is taken from the U.S. Navy Diving Manual (Table 3) and has been adopted by Occupational Safety and Health Administration (OSHA) for commercial application.

2. In addition to the purity standards of the Navy, the CGA defines nine grades of air, including atmospheric air and air synthesized by blending O_2 and nitrogen (Table 4). As recommended by the CGA, Table 5 shows the typical uses for the different grades of air. The purity of the air for chamber application must meet CGA Grade E as a minimum.

3. To determine the purity of a gas, a volume of air must be analyzed by gas chromatography or mass spectrometry. The analyzer must be capable of determining the specific components with a sensitivity of 0.1 ppm or 20% of the specified maximum amount of the component, whichever is greater. If the facility cannot afford an expensive gas chromatograph or mass spectrometer, it is recommended that air samples be sent to a chemical or air testing lab. The volume of air

Table 3: Purity Standards of Compressed Air for Human Consumption

Constituent	U.S. Navy/OSHA
Oxygen (O_2), percent by volume	20–22%
Carbon dioxide (CO_2), by volume	1,000 ppm (max)
Carbon monoxidee (CO), by volume	22 ppm (max)
Total hydrocarbons (as CH_4), by volume	22 ppm (max)
Oil, mist, particulates; weight/volume	5 mg/m^3 (max)
Odor	not objectionable
Separated water	not objectionable
Total water, weight/volume	not objectionable

required to perform the analysis should be contained in a single sample container and be sufficient to perform analysis for all the desired constituents. The volume required to perform the analysis may vary slightly from one analyzer to another but as an average must contain approximately a cubic foot (28.3 liters) of air. The pressure of the air must be equal to the air storage pressure.

4. The sample container must be a pressure bottle rated at or greater than 1.5 times the sample pressure and must comply with Department of Transportation (DOT) specifications. The container must be equipped with a shut-off valve which conforms to American National Standards Institute B57 and pressure rated at or above 1.5 times the sample measure. The gas sample container (Fig. 3) must be cleaned of all contamination before filling with the air sample. To ensure that no atmospheric contamination is contained within the sample container, a vacuum is pulled on the container with the supply shut-off valve closed. The connection between the sample container and the source must be connected positively to ensure that only the source air is transferred into the container. No regulator is used between the source and the sample container.

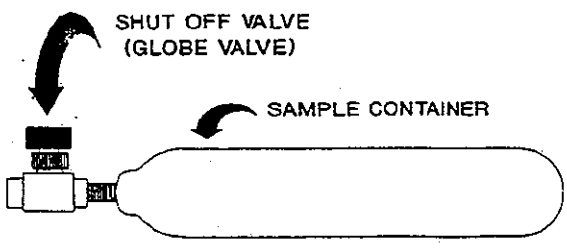


Fig. 3—Gas sample container.

TABLE 4. Grades of Air Purity (Compressed Gas Association, Arlington, VA)

	TYPE I (GASEOUS)									TYPE II (LIQUID)	
Limiting Characteristics	GRADES A	B	C	D	E	F	G	H	J	A	B
$\%O_2$ (v/v) Balance Predominantly N_2 (Note 1)	atm.	atm.	atm./ 19.5-23.5	atm./ 19.5-23.5	atm./ 19.5-23.5	atm./ 19.5-23.5	atm./ 19.5-23.5	atm./ 19.5-23.5	atm./ 19.5-23.5	atm./ 19.5-23.5	atm./ 19.5-23.5
Water		none condensed (note 1)	note 2	note 2	note 2	note 2	note 2	note 2	1 -10.4°F		note 2
Hydrocarbons (condensed) In Mg/m^3 of gas at NTP (Note 3)		note 1	5	5	5						
Carbon Monoxide			50	20	10	5	5	5	1		5
Odor			see 5.1.5	see 5.1.5	see 5.1.5	see 5.1.5	see 5.1.5	see 5.1.5	see 5.1.5		none
Carbon Dioxide				1000	500	500	500	500	0.5		5
Gaseous Hydrocarbons (as methane)						25	15	10	0.5		10
Nitrogen Dioxide							2.5	0.5	0.1		0.5
Nitrous Oxide									0.1		
Sulfur Dioxide							2.5	0.5	0.1		0.5
Halogenated Solvents							10	1	0.1		1
Acetylene									0.05		0.5

Note: All units are measured in parts per million (ppm).

Note 1. Inverted cylinder (valve at bottom) and ambient temp at or above 32°F air is draw off at a rate barely audible for one minute through a white rag. No oil present or discoloration.

Note 2. The water content of compressed air may vary with the intended use from saturated to very dry.

Table 5: Typical Uses for Different Grades of Air

Grade	Use
A, gaseous and liquid	not respiratory
B, gaseous	not respiratory
C, gaseous	not respiratory
D	minimum industrial grade
E	minimum sport diving grade
F	minimum respiratory grade

Air Compressor

1. Although air may be produced by mixing pure N_2 and O_2, the most common method of production is accomplished by compression of atmospheric air. The mixture of pure N_2 and pure O_2 is commonly used in research applications where minute impurities and trace gases are undesirable.

2. Compressed atmospheric air, on the other hand, contains the natural trace gases plus impurities which vary with geographic location or with proximity to industrial areas or automotive pollutants. When air is compressed during periods of rain or extremely high humidity, the water content of the air is raised considerably. This, in itself, is not considered an impurity but will affect operation of the treatment chamber control systems. The quality of the air taken into the compressor is the major factor in governing the purity of air generated. The most common compressor used in health care facilities to produce compressed air for human respiration is the piston or rotary type compressor generating air pressures up to 300 psig. These compressors may be internally lubricated by oil, by water, by water with soap solution, by natural mineral oils, or without lubricants by the use of Teflon-coated pistons. Compressors with Teflon piston rings are not lubricated.

3. The compressor system lubricated with oil is most commonly used and in general has longevity over all other types, except the Teflon-coated pistons. The oil recommended by the equipment manufacturer for general use is a petroleum product, but in the production of air for human respiration it is desirable to use a synthetic lubricant that is nontoxic and is compatible with O_2 (e.g., Anderol, Huls America, Piscataway, NJ).

4. The compressor intake must be located where it will not be contaminated by strong odors, undesirable contaminants, carbon monoxide from automotive exhaust, boiler exhausts, diesel exhaust from emergency generators, or exhaust from an engine used to drive the compressor. The suction of the compressor should, if possible, be located outside the building.

5. The compressor intake should be equipped with a suction filter or filters that will remove solids such as dirt, dust, and airborne impurities. The intake filter must be of the dry type. Oil-bath-type air filters are prohibited. The size of the suction piping must be large enough not to cause compression starvation. As a general rule, the inlet should be doubled in size every 10 feet (3.3 m) between the compressor first stage and the inlet filter.

6. The compressor discharge should be cooled before filtration, storage, and/or use. Cooling of the compressed air will first remove most of the condensate, and by reducing the temperature of the air, the elements of the filters will not be burned and destroyed. Filters are required on the discharge side of the compressor after the cooling coil to remove water, oil vapors, odors, and other contaminants and particulates before storing or direct use.

7. In most cases an activated charcoal filter will remove oil vapors and odors. Carbon monoxide may be removed by first converting it catalytically to carbon dioxide then removing the carbon dioxide. A catalytic filter cartridge such as produced by Delmonox (available from Deltech Engineering, Inc, Century Park, P. O. Box 667, Newcastle, DE 19720; 302/328-1345) may be used. All filter housings must be equipped with a drain valve system to evacuate the condensate and oil particulates. The filter will also remove water and must be drained periodically.

Air Storage Flasks and Supply Piping

1. After the filter system, the air should be plumbed into air storage flasks. These storage flasks not only act as a receiver necessary to supply sufficient volume for the intended compression or ventilating of the treatment chamber, but also act as a pulsation dampener to the chamber and an additional condensate collector.

2. The volume of air required for emergency operation should be a minimum of 3 times the volume of the treatment compressed to its maximum operating depth. For example, if a monoplace treatment chamber contains 50.8 cubic feet (1,454 liters) at 3 atm abs, the stored air volume must equal twice the chamber

volume plus another chamber volume for driving force. This equals a total of 152 cubic feet (4,304 liters) of compressed air.

3. Volume tanks are designed and manufactured in a variety of sizes and configurations to meet the individual needs and space requirement of the facility.

4. The storage flasks must be approved vessels that are designed for pressures. The air storage flasks must be constructed to meet the regulations of the American Society of Mechanical Engineers (ASME) pressure vessel code, Section VIII, Division I and are registered with the National Board of Boiler and Pressure Vessel Inspectors.

5. The air storage volume tanks should be equipped with a resettable pressure relief valve set to lift at 10% above the working pressure of the volume tanks, a pressure gauge, and a condensate drain valve system. The condensate drain valve may be either a simple manual valve or an automatic drain valve system.

6. An automatic drain valve system is installed when it is inconvenient for a person to manually drain the condensate from the volume tank.

7. The piping from the compressors to the volume tanks should be sized to facilitate the flow of compressed air without causing excessive back pressure on the compressor.

CHAPTER VI: MONITORING AND LIFE SUPPORT

Lindell K. Weaver, M.D.

Introduction

1. This chapter presents patient monitoring techniques in the monoplace hyperbaric chamber (1–3). The first section describes established monitor-ing techniques and offers additional methods of patient monitoring in the monoplace hyperbaric chamber (MPHC). The severity of illness of the patient or the likelihood of the patient becoming unstable (hemodynamic and/or respiratory) during a hyperbaric oxygen (HBO_2) treatment will determine the level of monitoring that is required for the individual patient. All patients undergoing HBO_2 must be grounded to the already grounded chamber to minimize the risk of fire from static charge accumulation (Letter from Sechrist, Industries, Inc, 7 March 1989).

2. Life support in the MPHC is accomplished in a similar manner as in the intensive care unit (ICU). Kindwall and Goldmann (1) and Holcomb et al. (2) provided details of treating patients in the MPHC that are appropriate and helpful. Specific life-support issues relating to HBO_2 therapy in the monoplace chamber presented in this chapter include:

a. Adequate equipment and appropriately trained personnel to manage critically ill patients.
b. Transport of patients to and from the ICU and the HBO_2 unit.
c. Mechanical ventilation.
d. Air breaks with mechanical ventilation.
e. Intravenous support.
f. Use of suction.
g. Caveats of dealing with critically ill patients.

Patient Monitoring

1. Most patients treated with HBO_2 are monitored by direct observation. The respiratory rate and effort of breathing are evident. Occasionally, one can appreciate the pulse rate by observing the carotid pulse, the posterior tibial pulse, or the precordial apex beat should the chest be exposed. Agitation and anxiety are easily recognized and should prompt the attendant to consider central nervous system (CNS) oxygen toxicity. If a patient has a Foley catheter, urine output can be approximated, but since the collection receptacle is level with the patient in the chamber, complete drainage into it is not likely to occur.

2. In addition to the visual communication just described, voice communication is established by a microphone–speaker arrangement. Alert patients can describe sensations and feelings which are an important element of monitoring.

3. The cardiac rhythm is readily monitored during HBO_2 treatments. Most MPHCs offer an electrical pass-through for carrying physiologic signals from inside the chamber to a monitor located outside the chamber. A strip chart recorder is helpful to evaluate dysrhythmia. Some physiologic monitors can measure respiratory rates via changes in chest wall impedance recorded with the ECG electrodes (e.g., Marquette series 7010 monitor, Marquette Electronics Inc., Milwaukee, WI). This provides a useful method of monitoring respiratory rates continuously and includes the option of setting respiratory rate parameters that will initiate audio and/or visual alarms if the parameters are exceeded. Similarly, the electrical signal obtained from electroencephalographic (EEG) monitoring can be transferred out of the MPHC and recorded (3).

4. Blood pressure (BP) can be measured both noninvasively and invasively in the MPHC. Hemodynamically unstable patients or patients requiring intravenous pressors or antihypertensives should have their BP monitored continuously. For patients in which episodic BP measurement are clinically indicated, noninvasive methods are acceptable.

5. Drager (Dragerwerk AG Lübeck Werk Drückkammertechnik Auf Dem Baggersand 17, Postfach 150 149, D-2400, Germany) offers a noninvasive method of measuring BP during HBO_2 therapy with the use of an electronic stethoscope and inflation of the BP cuff from outside the chamber (Fig. 1).

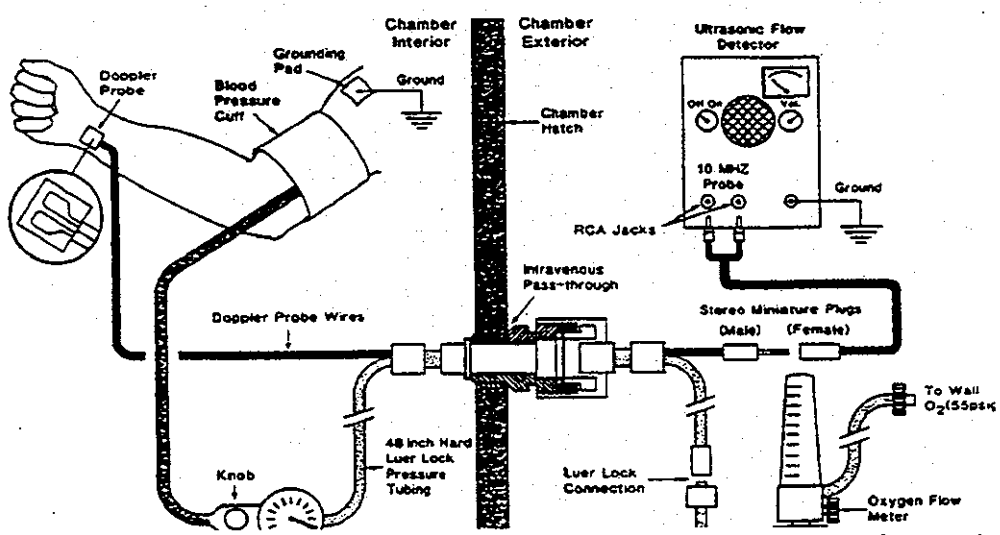


Fig. 1—Schematic of a noninvasive blood pressure monitoring system developed at LDS Hospital. A standard BP cuff and sphygmomanometer are placed inside the chamber. Blood flow is determined with a Doppler flow detector and ultrasonic monitor. The BP is measured by observing the sphygmomanometer while listening to the Doppler signal as the cuff is inflated and deflated from outside the chamber by adjusting the oxygen flow meter.

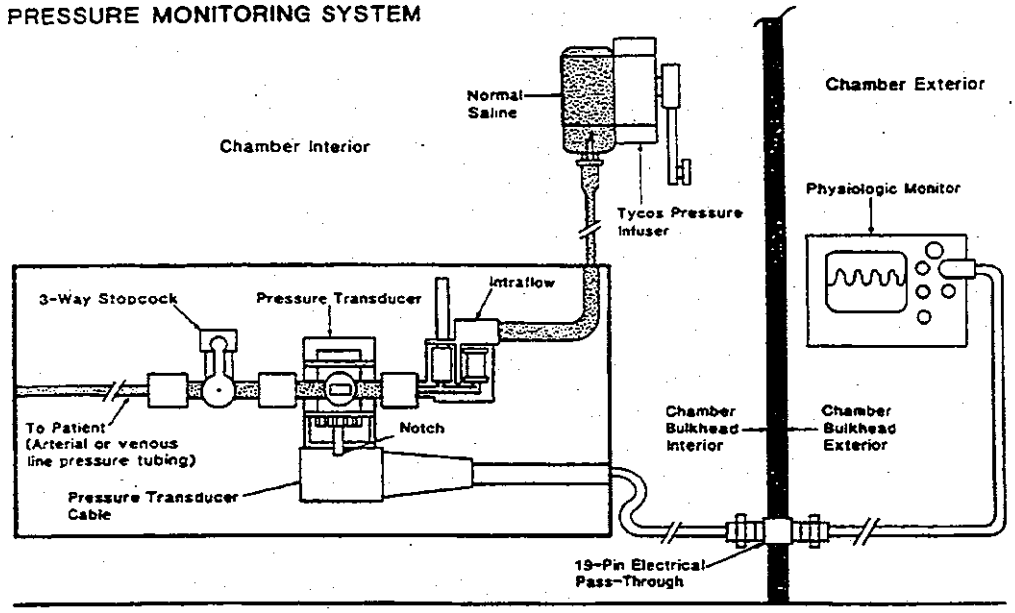


Fig. 2—Schematic of a pressure monitoring system that is used in the monoplace hyperbaric chamber. The Intraflo continuously flushes the catheter at approximately 3 ml/h at 300 mmHg pressure. A Tyros Pressure Infuser is placed inside the chamber to provide a 300 mmHg pressure source for the Intraflo. All connections should be luer-lock. The physiologic signal is passed out of the chamber via an electrical pass-through (e.g., 19-pin connector) to the physiologic monitor. Note the notch cut in the transducer cable (Fig. 3). (Weaver LK, courtesy of J.B. Lippincott.)

6. CAS Medical Systems (21 Business Park Rd., Branford, CT) has developed an electronic, noninvasive BP monitor for use in the MPHC, Oscillomate 1630. This monitor has been shown to be safe and

accurate (5) up to 3.0 atm abs. (7). The BP is measured using a differential mode rather than a gauge mode of reference. This is ideal for patients who require episodic BP determinations or those who have a contraindication to invasive arterial BP monitoring.

7. Continuous measurements from a pressure transducer (Fig. 2) can be accomplished (e.g., arterial, pulmonary artery, compartmental, or intracranial) (1,3). The arterial pressure monitoring system at the LDS Hospital requires a flush device (Intraflo III, no. 42002-01, Sorenson Research, 4455 Atherton Drive, Salt Lake City, UT) which continuously flushes the transducer (Transpac II, disposable transducer, no. 42557-01, Abbott Critical Care Systems, Abbott Laboratories, Hospital Products Division, North Chicago, IL) at 3 ml/h at 300 mmHg (8). The Intraflo requires a saline solution subjected to 300 mmHg pressure. The Tycos Pressure Infuser (Tycos Instruments, Inc, 95 Old Shoals Road, Arden, NC) accomplishes this. It is a spring-loaded device that maintains 300 mmHg pressure to the saline bag. This is placed inside the chamber. One caution, however, concerning the Tycos infuser is that a petroleum-based grease is used to lubricate a bearing inside the Tycos unit (9). The manufacturer, upon request, will change this grease to one acceptable for a high pressure O_2 environment. The electrical transducer cable is plugged into the electrical pass-through (19-pin connector in the Sechrist chamber) and, subsequently, the pressure monitor. The transducer must be able to reference to chamber pressure. This can be accomplished by cutting a notch in the cable at the transducer end (Fig. 3) or using a vented transducer (e.g., Cobe, Inc, Lakewood, CO).

8. An alternative method of flushing the arterial catheter is to connect the pressure transducer to an intravenous infusion set passed through the chamber which infuses solution at the specified rate. No Intraflo solution is used for the compartment and intracranial pressure measurements.

9. It is possible to obtain arterial blood gases from a patient in the MPHC (Fig. 4). The pH and Pa_{CO_2} values help to guide the adequacy of mechanical ventilation during a HBO_2 treatment. Pa_{O_2} values may be interpret-able, depending on the inspired partial pressure of O_2, the chamber pressure, the machine used to measure the sample, how quickly the sample was measured, and how it was technically obtained. In vitro

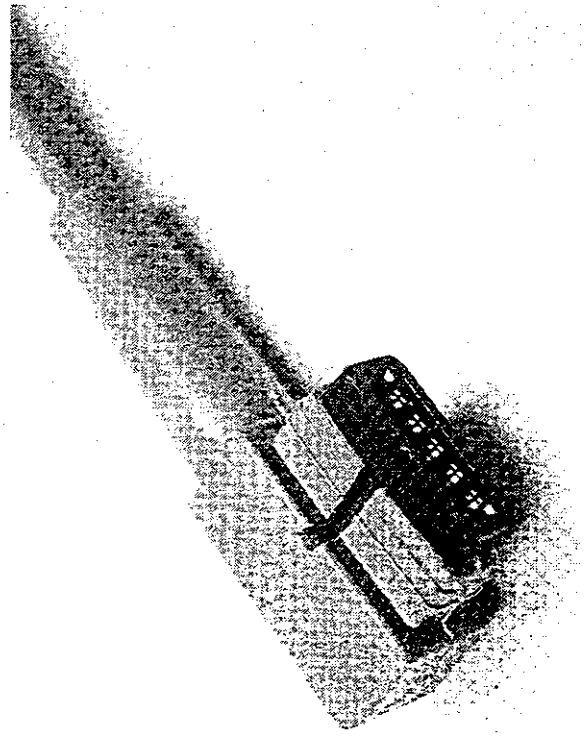


Fig. 3—Close-up view of a notch cut in the pressure transducer cable which allows equilibration of chamber pressure to the transducer. (Weaver LK, courtesy of J.B. Lippincott.)

investigations at the LDS Hospital demonstrate that the Radiometer ABL 330 blood gas analyzer (Radiometer, Copen- hagen, Denmark) can accurately measure HBO_2 tensions of tonometered saline and blood when analyzed at atmospheric pressure, if drawn in a sealed glass syringe and analyzed immediately (<1 min) (10). Further investigations with normal volunteers that had arterial blood withdrawn while compressed in the MPHC and analyzed immediately in a Radiometer ABL 330 at atmospheric pressure demonstrated arte-rial O_2 tensions in the predicted range (11). Minimizing the volume of dead-space in the lines and trans-ducer is important because one must draw out 3–4 times the system dead-space (generally 8–9 ml) before the sample is obtained. If heparinized, this blood may be given back to the patient (via a venous line). After obtaining the sample, the system is flushed with sterile saline (at LDS Hospital heparin has not been found necessary in arterial systems with continuous flush Intraflo). Ensure that air is not introduced into the line because it will dampen the pressure wave-form or could even cause a gas embolism (12). With this system, the Intraflo is

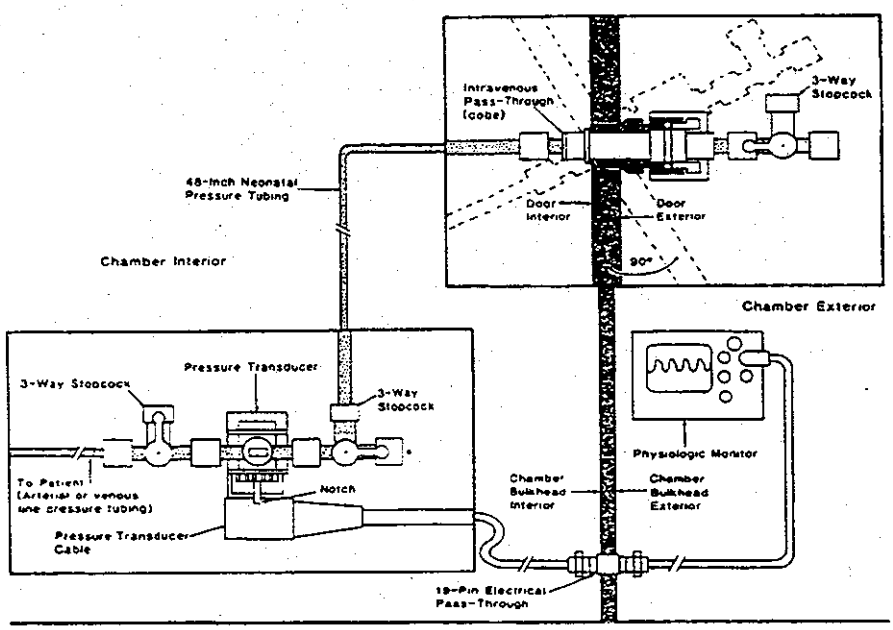


Fig. 4—Schematic of pressure monitoring system (see Figs. 2 and 3) that permits sampling of blood from a patient who is pressurized within the monoplace chamber. The Intraflo (denoted by ▲) can either be removed or the 3-way stopcock can be turned off to the Intraflo. Neonatal pressure tubing minimizes the system dead-space. The catheter needs to be periodically flushed from outside the chamber to keep it patent. (Weaver LK, courtesy of J.B. Lippincott.)

not used because one can force blood retrograde across the Intraflo when flushing the arterial set-up from outside the chamber. Only pres-sure tubing with luer-lock con-nections should be used. All connections need to be securely tightened to prevent the potential for leakage of blood, introduction of bacteria, and to prevent air entering the system, which could occur during flushing a system with a loose connection. Neonatal pressure tubing is available that has a smaller volume than that of the adult-sized tubing. For radial and femoral artery catheters a 48 inch (122 cm) length is adequate (no. 042-613-900, 48-inch neonatal luer-lock pressure tubing, Cobe).

10. It is also possible to monitor end-tidal carbon dioxide (E_tCO_2) in the MPHC. At LDS Hospital a POET E_tCO_2 side-stream monitor (Criticare Systems, Inc, Wankesa, WI) is used. This system has a catheter that passes through the chamber hatch with a conventional Cobe IV pass-through. In spontaneously breathing patients, the aspiration catheter is connected to a small caliber nasal cannula. Observations at LDS Hospital indicate that E_tCO_2 measurements can be obtained from spontaneously breathing patients compressed in the MPHC where E_tCO_2 is sampled via a nasal cannula, passed out of the MPHC, and analyzed at atmospheric pressure, but there is considerable variability in the E_tCO_2 value. As expected, the measurements demonstrate less variability if the E_tCO_2 is sampled from a two-way, non-rebreathing valve (Hans Rudolph, Inc, Kansas City, MO) fitted with a scuba mouthpiece while the patient wears a nose clip, or from an endotracheal tube. The E_tCO_2 value falls as a function of chamber pressure (e.g., the ideal or predicted E_tCO_2 equals the true E_tCO_2 multiplied by the absolute barometric pressure divided by the absolute chamber pressure). Preliminary observations in nine normal volunteers who had simultaneous measured arterial O_2 tension from atmospheric to 2.9 atm abs demonstrated a measured E_tCO_2 value that was within 4–7 mmHg of the predicted E_tCO_2 if sampled from a two-way, non-rebreathing valve. This system may be particularly useful for patients who are sedated during HBO_2 or who retain CO_2 chronically, and may serve as an apnea monitor. For intubated, mechanically ventilated patients, the E_tCO_2 monitor has proven useful to adjust the minute ventilation during HBO_2 treatment. In this

situation, the aspiration catheter samples gas from the proximal airway.

11. A flow-directed thermal-dilution fiberoptic pulmonary artery (Swan-Ganz) catheter can be used in the MPHC. It should only be used if pulmonary artery data are critically needed. The continuous presence of a physician (who is experienced in critical care and HBO_2) and a critical care nurse is recommended because critically ill patients may be unstable during HBO_2, and use of the pulmonary artery catheter and the number of pass-throughs (Table 1) require considerable attention to detail. This system only works with subclavian or internal jugular pulmonary artery catheters, preferably right-sided due to the length of the catheter.

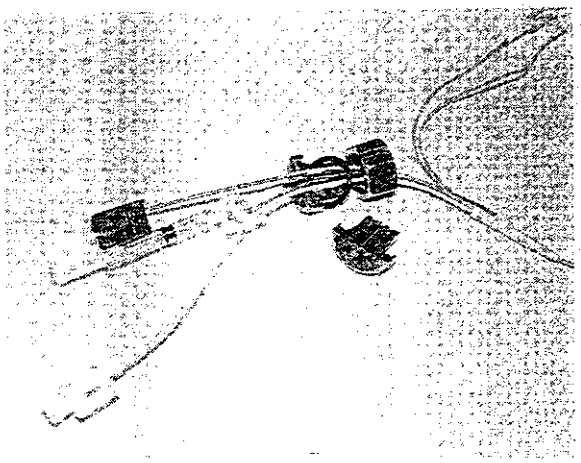
12. To monitor right atrial and pulmonary artery pressures, two separate transducers are necessary. It is also necessary to have a special pass-through plug machined to permit passage of multiple lines through the 13/16-inch (20.6 mm) holes located in the Sechrist MPHC hatch. A 13/16-inch-diameter bolt was cut in half down its long axis. Next, three grooves were machined in the split halves to just a fraction smaller than the tube diameters (Fig. 5). The oximetry fiberoptic cable, balloon port, and thermistor cable are passed out through one of the 13/16-inch holes in the Sechrist chamber hatch (after removal of the Sechrist IV pass-through port or blank plug). Then the three tubes are slid in from the outside sandwiched within the machined grooves between the two halves of the split bolt. A split nut is tightened from the inside of the hatch using a specially built socket and rachet (Figs. 5 and 6). These items were fabricated locally to LDS Hospital specifications. The fiberoptic oximeter is then connected to its cable and monitor. This should be taped to the chamber hatch in such a way as to prevent kinking of the fiberoptic cable, which can damage it. In a similar fashion, another split bolt that allows four hard pressure tubes to be passed through one chamber hatch hole will provide adequate i.v. access to use the pulmonary artery catheter (Table 1, Fig. 7). A specially designed pass-through plug is used to provide the ventilator gas supply suction and to permit E_tCO_2 monitoring (Fig. 8). The pulmonary artery catheter is passed out of the chamber as described above after sliding the patient into the chamber, before closing the hatch. The transducers (right atrial and pulmonary artery) are taped at the reference position (right atrial level) just inside the chamber hatch. Pulmonary artery blood will need to be obtained to calibrate (in vivo cal) the pulmonary artery fiberoptic oximeter. This is done after the chamber is pressurized, which facilitates obtaining the sample due to the pressure gradient (the sample is pushed out of the chamber when the patient is at greater than atmospheric pressure). One foot (31 cm) of luer-lock pressure tubing is connected to the right atrial transducer (as in Fig. 4) and passed out through the 4-in-1 plug (Fig. 7). All lines that blood does not need to be aspirated from should have one-way back check valves in place (no. 042-617-301, Hyperbaric Valve, Cobe).

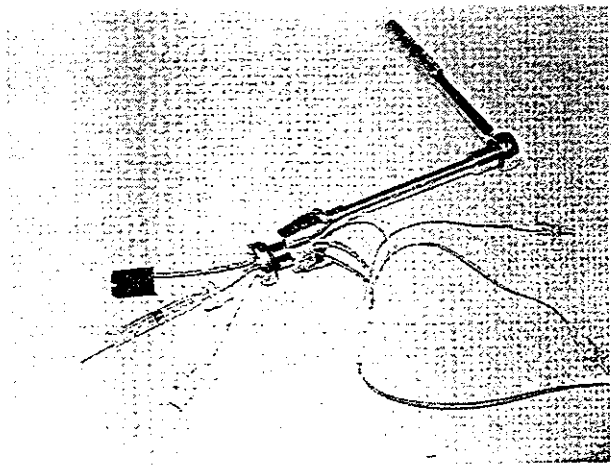
13. To obtain the pulmonary capillary wedge pressure, sufficient air to inflate the pulmonary artery catheter balloon to the same volume as the balloon holds at atmospheric pressure is pushed into the balloon. At atmospheric pressure the balloon requires up to 1.5 ml. The catheter dead-space is 0.25 ml. At 3.0 atm abs, one would have to push 5.25 ml of air [(1.5 + 0.25) × 3.0] from outside the chamber to fill the balloon to the same size as 1.5 ml at atmospheric pressure. Before using a pulmonary artery catheter in

Table 1: Examples of the Function of the Sechrist 2500B Hatch Pass-through Ports When Using a Pulmonary Artery Terminal-Dilution Fiberoptic Catheter, Suction System, and Mechanical Ventilator[a]

Pass-through	Function
Top	arterial sampling
Second	pulmonary arterial sampling
Third with split-bolt	pulmonary arterial catherter:
	oximeter fiberoptic cable
	balloon
	thermister
Fourth with split-bolt	four i.v.
	right arterial line for thermo-dilution cardiac output
	i.v., e.g., TPN
	i.v., e.g., dopamine
	i.v., e.g., maintenance, paralytics, etc.
Fifth with modification	suction
	ventilator
	ventilator venturi bag
	miscellaneous, e.g., gas sampling port

[a]This number of pass-through lines requires special pass-through ports.





Figs. 5 and 6—Specially designed split bolt and nut that have been machined to sandwich snugly over the fiberoptic cable, pulmonary artery balloon catheter, and thermister cable of a thermal-dilution, fiberoptic pulmonary artery catheter. After the patient is slid inside the Sechrist 2500B monoplace chamber, these three items are passed out of the chamber through the upper 13/16-inch (20.6 mm) hole in the hatch of the Sechrist 2500B chamber hole (after removal of the i.v. port). The rubber O-ring is placed over the three cables followed by each half of the split bolt, which is then inserted into the chamber door hole. The split nut is slid over the cables and tightened down from the inside. (Weaver LK, courtesy of J.B. Lippincott.)

a patient, this technique should be practiced by using a discarded catheter that has been passed into a pressurized chamber. After measuring the pulmonary capillary wedge pressure, the catheter balloon lumen must be left open to prevent rupture during ascent from expansion of the remaining gas in the balloon.

14. The pulmonary artery, right atrial, and arterial pressure waveforms may be slightly dampened in this configuration, but the measurements should still be

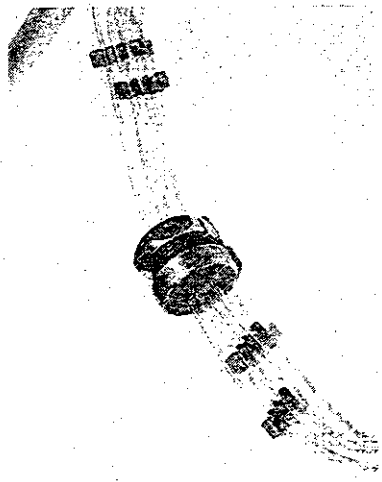


Fig. 7—Specially designed split bolt and nut similar to Fig. 5 but designed to pass up to four pressure tubes out of the chamber. Insertion through the hatch is similar to that of the pulmonary artery catheter. (Weaver LK, courtesy of J.B. Lippincott.)

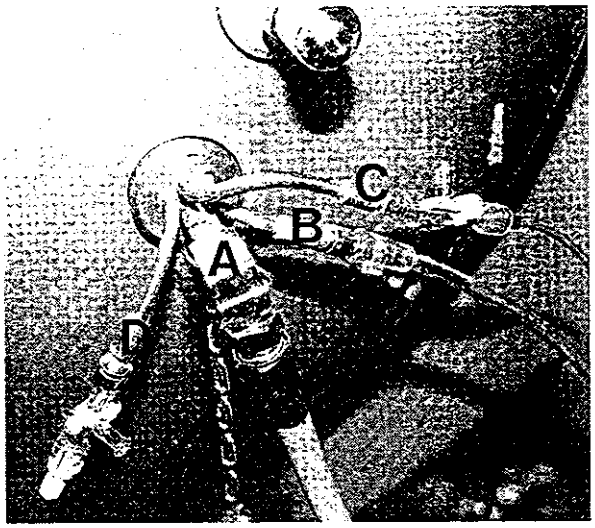


Fig. 8—Specially designed pass-through plug so that the ventilator gas supply (A), *the ventilator venturi bag gas supply* (B), *and suction pass-through* (C) *can all be passed out of the chamber through one* 13/16*-inch (20.6 mm) hole. An additional port is available for gas sampling* (D) if needed. (Weaver LK, courtesy of J.B. Lippincott.).

adequate for interpretation if the dynamic response of the system is tested and found to be acceptable (13). Pressure tubing lengths should be as short as possible and all air bubbles eliminated from the lines and transducers to minimize the degree of dampening. If

the waveform remains dampened after thoroughly flushing the system with sterile saline, inspect for small bubbles (usually at junctions and connections), a loose or broken luer-lock connection, or even cracks in the transducer or pass-through.

15. Cardiac output determinations are made by using the thermodilution technique. A 12-inch (31 cm) extension tube (no. 040-101-005, Cobe) is connected to the right atrial pressure transducer. This tube is passed out of the chamber via the four-grooved split bolt (Fig. 7). A cardiac output syringe and valve set-up (CO-Set II, Closed Injectate Delivery System, model 93-500, American Edwards Laboratories, AHS del Caribe, Inc, Anasco, PR) is connected to the 12-inch extension tube on the outside of the chamber. This additional dead-space does not change the cardiac output determination (personal observation, LKW). The 10-ml syringe plunger needs to be forcefully pushed when the patient is pressurized to obtain an adequate change in temperature vs. time wave-form that is used to calculate the cardiac output. This curve should be displayed on the monitor to choose the best curves for adequate interpretation.

16. To obtain the arterial and pulmonary artery oxygen contents (C_aO_2–C_vO_2), blood is aspirated retrograde across the arterial and pulmonary artery pressure transducers (Fig. 4). (The Intraflo can be removed because the lines can be flushed from outside the chamber.) After sampling, sterile saline is flushed through the lines and transducers. When obtaining the sample it is useful to use a three-way stopcock connected to the i.v. pass-through on the outside of the hatch. By **carefully** turning this stopcock to the appropriate position, the direction of blood flow can be directed into a 10-ml luer-lock syringe (dead-space, previously heparinized) or into a 3-ml glass syringe (sample). After sending the sample immediately to the blood gas lab, connect a luer-lock 3-ml syringe to the three-way stopcock. With the stopcock off to the patient, push blood from the 10-ml syringe into the 3-ml syringe. Then turn the stopcock off to the 10-ml syringe and push the blood back to the patient. With a patient who is pressurized in the chamber, it is much easier to push blood (or medications) with a 3-ml syringe than with a 10-ml syringe (Pressure × Area = Force). Alternate this until the blood has been given back to the patient, then connect a 10-ml syringe filled with sterile saline to the position where the former 10-ml syringe was. Continue pushing saline through the system to clear the i.v.tubing and transducer of blood. Periodically, push 1 or 2 ml of saline through the line to keep the catheter patent as this system does not use an Intraflo. All pressure transducers should be zeroed to the appropriate reference level inside the chamber **before** compression.

17. Transcutaneous oxygen (T_cO_2) measurements can be carried out in patients being treated in the MPHC. Radiometer of Copenhagen supplies models TCM-2 and TCM-3 which are comparable and have been approved for use with monoplace chambers. Special cabling is required.

18. Tissue gas measurement can be obtained from patients undergoing HBO_2 treatments (15). Presently, this technique is limited to clinical investigations. Should appropriate advances in the technical aspects of tissue gas measurement during HBO_2 be made, these measurements will help determine optimal HBO_2 treatment pressures and frequency.

Life Support in the Monoplace Chamber

1. The hyperbaric unit should have adequate equipment to deal with patients who are treated by that unit. For example, if the unit does not have life support equipment available because it is an outpatient HBO_2 unit, then it would be inadvisable for such a unit to accept unstable or critically ill patients. If the HBO_2 unit accepts critically ill patients, then it should have equipment similar to that available in an intensive care or emergency department. This includes monitors (ECG, blood pressure, oximeters, end-tidal carbon dioxide, etc.), wall suction and vacuum regulators, a defibrillator, a ventilator, airway management equipment, Advanced Cardiac Life Support (ACLS) drugs, controlled drugs for sedation and analgesia, and intravenous catheters, tubing, and solutions for both adult and pediatric patients. Wound debridement and dressing supplies should also be stocked in the HBO_2 unit.

2. Likewise, the HBO_2 unit needs to be staffed with appropriately trained personnel. This includes physicians, nurses, respiratory therapists, and others, all of whom must possess special training in the effects, indications, and risks of HBO_2. These individuals need to be thoroughly familiar with the MPHC and the special equipment used with the chamber. This is especially important in the unstable and critically ill patient treated in the MPHC where physicians, nurses, and

therapists with critical care and hyperbaric medicine training use a team approach to support critically ill patients in the MPHC.

3. The transport of critically ill patients from the ICU to the chamber and back to the ICU is associated with risks (16). (Ideally, the MPHC should be adjacent to the ICU to facilitate the HBO_2 treatment of ICU patients.) Portable monitors, a portable ventilator, portable i.v. infusion pumps, and a well-trained staff are important elements of moving critically ill patients to and from the MPHC unit and the ICU.

4. If patients exhibit an altered mental status they should be physically restrained during treatment in the monoplace chamber to prevent them from pulling off ECG leads, intravenous catheters, or extubating themselves (17). I recommend that myringotomies should be performed or tympanotomy tubes inserted before compression on intubated patients to reduce the risk of middle ear barotrauma. However, a clinical trial comparing myringotomies vs. no myringotomies in unconscious and/or intubated patients has not been performed. Until results of such a trial are available, the treating physician will need to individualize this decision. If airway patency is questionable, the patient should be intubated before HBO_2 therapy in the MPHC to lessen the risk of complications such as aspiration, upper airway obstruction, or the development of hypercapnia, a risk factor for CNS O_2 toxicity (18).

5. The endotracheal (ET) tube of intubated patients undergoing HBO_2 therapy needs to have the cuff filled with saline before compression to prevent compression of the air-filled cuff, which could cause a leak and/or make the seal ineffective. Also, the ET tube should be well secured and all airway connections checked for tightness before treatment. If the ET tube is of insufficient internal diameter, an adequate minute ventilation and adequate exhalation may be difficult to achieve (because of increased flow resistance), particularly during HBO_2, due to the increased gas density and limitations of the monoplace mechanical ventilator (*see* below).

6. Three ventilators can be used in the monoplace chamber: the Sechrist 500A, the Drager Oxylog MOD, and a modified Bennett PR-2 (Dr. Allen Feingold, South Miami Hospital, Miami, FL). In the future, other ventilators may become available for use in the MPHC. The performance characteristics of the Sechrist 500A ventilator will be described (19).

7. The Sechrist 500A ventilator is a pneumatic, time-cycled ventilator that allows adjustment of flow, inspiratory time, and expiratory time. Supplying the control module with an O_2 source of the appropriate pressure is important. This ventilator requires at least 65 psig (4.42 kg/cm^2), and in some instances up to 85 psig (5.78 kg/cm^2) source gas pressure to function adequately. This exceeds the wall pressure of most hospitals (20), so an auxiliary gas source (e.g., large oxygen cylinders) to supply the ventilator is suggested.

8. To set up the ventilator for a patient, a test lung that approximates the patient's lung compliance (C_L) is connected to the ventilator circuit. The ventilator peak airway pressure relief valve is adjusted to approximately 10–15 cmH_2O above the patient's peak airway pressure. The control module knobs are positioned to deliver the appropriate minute ventilation (V_E). Once the patient is mechanically ventilated with the hyperbaric ventilator, an arterial blood gas is suggested. Positive end-expiratory pressure (PEEP) can be applied by placing PEEP valves on the expiratory circuit. "Occult" PEEP with chamber pressurization has been reported (21). With using a Downs PEEP valve (Vital Signs, Inc, 20 Campus Road, Totowa, NJ), PEEP generally is increased about 3 cmH_2O over that expected, with a particular Downs PEEP valve at a chamber pressure of 2.4 atm abs (personal observation, LKW). Airway pressure should be followed continuously with a manometer. As the chamber pressure is increasing, flow and inspiratory time are manipulated to maintain a constant tidal volume. Tidal volume (V_T) is a function of chamber pressure (P_{CH}), C_L, control module inlet pressure (P_{IN}), and probably airway resistance. A considerable reduction in V_T occurs with chamber pressurization if the ventilator is not properly adjusted during treatment (Fig. 9). Similarly, adjustments will need to be made if the patient's lung compliance changes. The V_T should be continuously monitored with a spirometer calibrated to the HBO_2 environment. A method of doing this has been described (19). The patient should be decom-pressed slowly (<2 psig/min), particularly as the patient approaches the surface (<20 fsw or 9 psig), to allow adequate elimination of expanding alveolar gas. In patients with lung disease, the ventilatory rate should be reduced during decompression to provide additional time for exhalation. Also, flow rates are usually

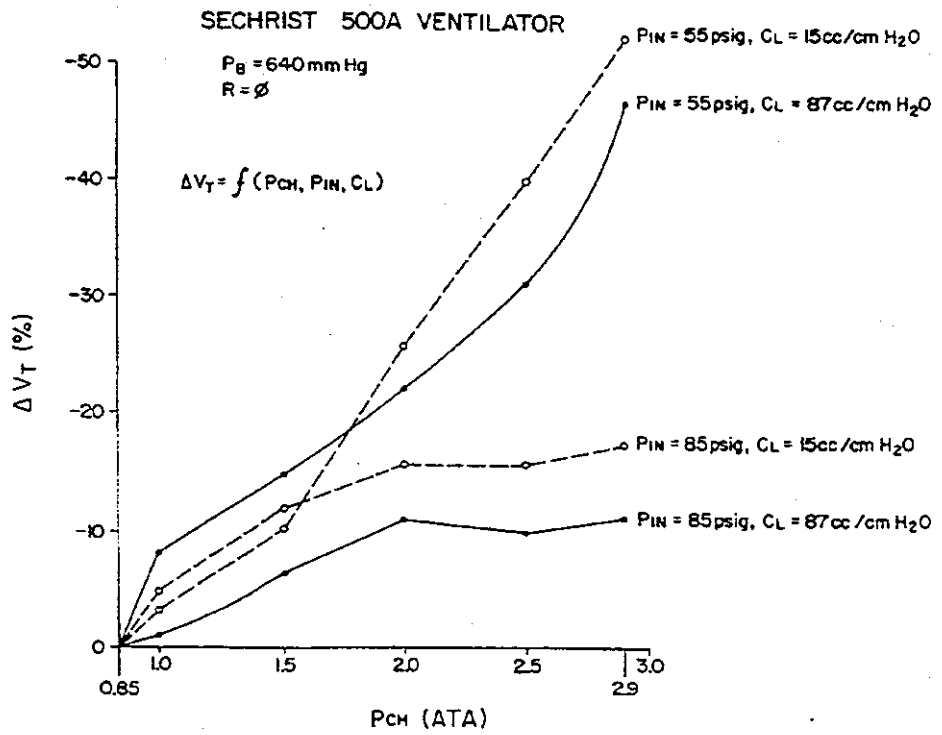


Fig. 9—Percent change in tidal volume (ΔV_T) *is plotted as a function of chamber pressure* (P_{CH}) *for lung compliance* (C_L) *15 and 87 ml/cmH_2O (12).* Dashed lines *and* solid lines *represent two families of curves defined by the ventilator inlet pressure* (P_{IN}). *Although not depicted, the* ΔV_T *for* C_L = 32 and 61 ml/cmH_2O *fall within the boundaries shown here (19). Barometric pressure* (P_B) *is as shown. Airway resistance (R) = 0.*

increased, allowing a shorter inspiratory time to maintain the same V_T, thereby increasing exhalation time. These maneuvers have not caused pulmonary barotrauma in intubated, mechanically ventilated patients with chronic lung disease, adult respiratory distress, asthma, and aspiration pneumonitis (personal observation, LKW). However, a death due to pulmonary barotrauma and arterial gas embolism associated with routine monoplace chamber decompression has occurred in a nonintubated patient with significant pulmonary parenchymal disease and fibrosis who was treated with HBO_2 for a problem wound (22). Careful consideration of the potential for pulmonary barotrauma in patients with preexisting pulmonary disease is important before giving HBO_2 therapy.

9. The Sechrist 500A ventilator is particularly limited at high V_E (>15 liters/min) and at high chamber pressures (>2.2 atm abs). Monitoring arterial blood gases during HBO_2 treatment of such patients is reasonable as the pH will become acidemic if there is inadequate alveolar ventilation. Some patients cannot be ventilated adequately if their V_E is high in the face of acidemia. If supplemental bicarbonate is administered to buffer hydrogen anions to reduce the acidemia, an elevation in the Pa_{CO_2} would result (23). This raises the potential for central nervous O_2 toxicity (18). Consequently, the risks and benefits of this intervention must be carefully considered before it is used.

10. Appropriate sedation and even paralysis may be necessary to treat intubated patients. If difficulty is experienced in matching the patient to the Sechrist 500A ventilator due to limitations in control functions, it may be safer to paralyze the patient. In the non-paralyzed patient, pulmonary barotrauma may occur if the patient coughs against the ventilator or receives a mechanical breath after taking a full spon-taneous breath. A seizure will not be obvious in a paralyzed patient. To reduce the risk of a seizure, air breaks may be provided to mechanically ventilated patients. This is accomplished with the Sechrist 500A ventilator by

placing ananesthesia bag around the 500A entraining venturi valve and filling the bag from a source of air or O_2 external to the chamber (24) (Fig. 10). During air breaks it is important that the patient not breathe spontaneously to avoid increasing his airway O_2 concentration by pulling in O_2 through the one-way (spontaneous ventilation) valve located on the ventilator block. During air breaks, both the ventilator and venturi bag gas sources are air. It takes 15 breaths (V_t = 500–700 ml) to clear the dead space of the system to achieve the new O_2 concentration.

11. To infuse an i.v. solution into a patient in the monoplace chamber, either the solution needs to be put inside the chamber and the infusion rate controlled from outside the chamber, or the infusion needs to be pumped under enough pressure to overcome the chamber pressure, patient's venous pressure, and flow resistive pressures from outside the chamber. Drager uses the former technique where the infusion is pressurized with a cuff whose pressure is regulated from outside the chamber. Most systems in the United States, however, use the latter method (Fig. 11). The IVAC 530 (IVAC Corp., San Diego, CA, available from Sechrist, Inc., Reimers Engineers, Inc., and American IV Products, Inc, 7485 Shipley Avenue, Harmans, MD) is a peristaltic pump that can deliver over 30 psig. This permits infusions of solutions even if the MPHC is compressed to 3 atm abs. Abbott/Shaw makes an i.v.

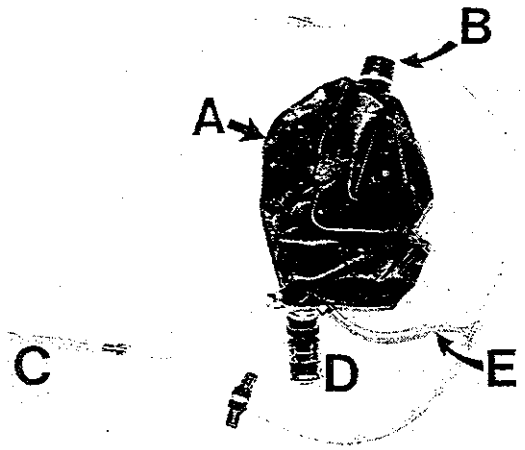


FIG. 10—Anesthesia bag (A) *secured to venturi valve* (B) *with Tygon tie. The bag is filled from a gas source external to the chamber via a Cobe i.v. pass-through* (C). *A one-way Bird check valve* (D) prevents over-expansion of the bag. The ventilator block gas driving tube (E) *goes through the bag and connects to the venturi valve nipple* (24).

infusion pump specifically designed for monoplace hyperbaric chamber use. It is their Lifecare model 3HB (Abbot Laboratories). For intermittent i.v. drug injections, it is preferable to inject the drug using a three-way stopcock located at the chamber hatch. If i.v. medications need to reach the patient immediately, an appropriate volume of infusate needs to be pushed to clear the tubing dead space (e.g., 6 ml if using the 6-foot, adult Cobe HBO_2 i.v. setup, 15 ml if using the standard Sechrist IV setup). This volume needs to be considered if giving frequent intermittent doses, especially in a patient with renal failure or in a small child. Cobe also offers neonatal pressure tubing that has less dead space (3 ml in a 6-foot length). When using the IVAC 530, ensure the appropriate flow rate is set. The volume of fluid administered is a function ofthe drip chamber type and the pump setting. A conversion chart for different drip chambers needs to be available (Fig. 12). This is particularly important for drugs such as dopamine, nitroprusside, dobutamine, or potent analgesics or sedatives that may be given by continuous i.v. infusion. The patient must never receive an inadvertent bolus of drugs. When initiating the patient on these medications during a MPHC treatment the tubing dead space has to be cleared before the drug reaches the patient. When initiating a drug like dopamine on a patient who is compressed, inject about 0.5 ml of methylene blue into the line, followed by the dopamine solution. The dopamine is injected with a syringe while observing the methylene blue advance in the i.v. When the methylene blue reaches the patient, the dopamine infusion is begun at the appropriate rate. This allows for rapid initiation of therapy without administering a bolus of a potent pressor to the patient. After the HBO_2 treatment, the i.v. line is disconnected near the pass-through, slid out of the pass-through, and reconnected to the tubing while sterility is ensured. By leaving the i.v. tubing connected to the patient the next HBO_2 treatment is more rapid and the cost of replacing tubing and pass-throughs is saved. We typically change the setups in 24-h intervals. The Cobe Tri-clip i.v. tubing clamp (no. 041-084-000) helps keep multiple i.v. lines in order and untangled. The IVAC 530 can also be used to pump enteral nutrition (e.g., osmolyte) through an i.v. pass-through and subsequently be connected to a patient's duodenal or jejunal feeding tube. This should be considered, in particular, in diabetic patients who are taking insulin.

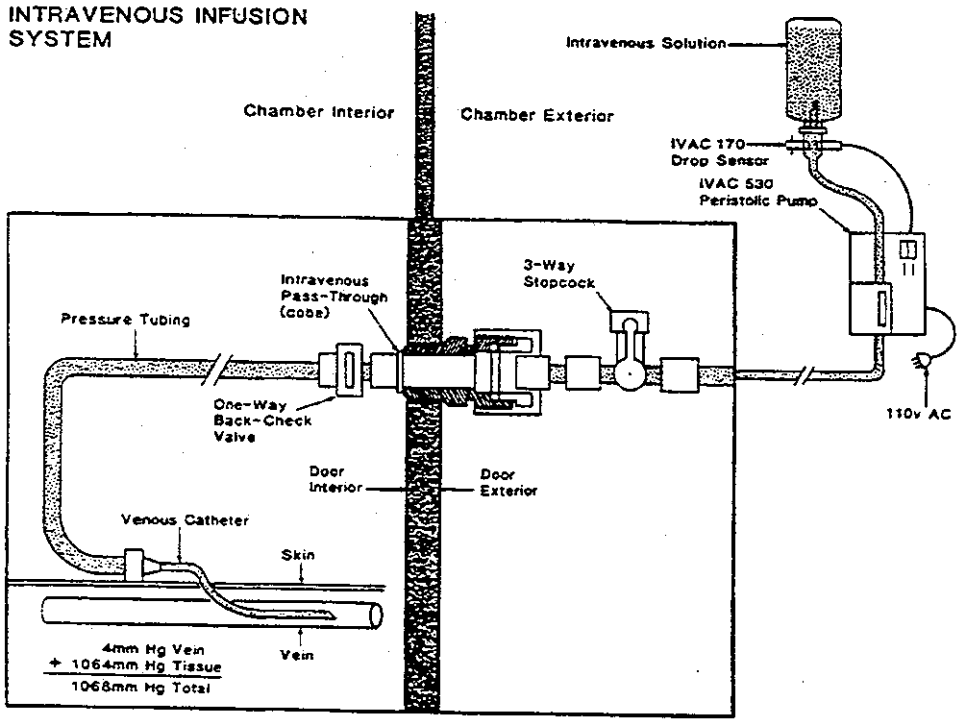


Fig. 11—Schematic of i.v. system for providing i.v. infusions to patients who are compressed within a monoplace chamber. Typical pressures at 2.4 atm abs (atmospheric gauge pressure = 0), the pressure in the tubing between the i.v. AC pump and the i.v. pass-through is the sum of the venous pressure, the chamber pressure, and flow resistive pressure, which in this case equal 1,068 mmHg. (Flow-resistive pressures are neglected in this example.) (Weaver LK, courtesy of J.B. Lippincott.)

12. The IVAC 530 has difficulty pumping blood at a rate much over 100 ml/h, particularly at high chamber pressures. Also, the latex tip on blood tubing may rupture if placed between the pump and the chamber, due to the pressure generated. Volume loading near the end of HBO_2 treatment in septic patients should be considered because hypotension and cardiovascular instability are common as the patient switches from the hyperoxic environment of the chamber to the normoxic, normobaric environment. Septic patients, especially those with a limited cardiac output, are particularly susceptible to this problem. Transfusion of blood, plasma, or albumin seems to decrease the hypotension encountered after HBO_2. Crystalloid may be acceptable for intravascular volume expansion if the patient does not have a pulmonary capillary leak syndrome. For blood, albumin, fresh frozen plasma, or platelet transfusions, a cardiac output set-up (CO-Set II, American Edwards Laboratories) can be modified to permit rapid, manual infusion. The cardiac output set-up allows a 12-ml syringe to fill with fluid from one source and inject it into another by way of a junction device that directs fluid flow with one-way valves. The unit of blood is connected to standard blood tubing. The blood tubing is cut near the distal tip (using sterile scissors) and connected to the fitting near the proximal tubing on the cardiac output setup by pulling the tubing apart at this fitting. This allows an easy method of pulling blood into the syringe and pushing it to the patient. A unit of blood (approximately 250 ml) can be infused in less than 5 min in this fashion.

13. Some critically ill patients may require multiple i.v. Special plugs that allow more than four i.v. to be used simultaneously in the Sechrist MPHC can be made (Fig. 7 and Table 1). Obviously, without these special plugs the number of existing pass-through ports in the typical monoplace chamber is limited to four (three if a ventilator is used). Without these special plugs, decisions will have to be made regarding

INFUSION PUMP START-UP PROCEDURE

FOR DETAILED INSTRUCTIONS, REFER TO USER INFORMATION

1. START I.V. ACCORDING TO STANDARD PROCEDURE.
2. PROPERLY POSITION DROP SENSOR ON DRIP CHAMBER.
3. SET PRESCRIBED RATE OF INFUSION ON DROPS PER MINUTE SELECTOR.
4. OPEN PUMP DOOR, PLACE I.V. TUBING BETWEEN GUIDES. MAKE SURE THAT DIRECTION OF FLOW IS FROM TOP TO BOTTOM AS INDICATED BY ARROW.
5. CLOSE DOOR AND OPEN CLAMP ON I.V. TUBING.
6. TURN INSTRUMENT "ON" BY DEPRESSING ON/OFF BUTTON.
7. PRESS START BUTTON TO START INFUSION.

CAUTION: • CLOSE I.V. SET CLAMP BEFORE OPENING PUMP DOOR.
• MAXIMUM RECOMMENDED RATE: 200 ml PER HR.

NOTE: FOR NORMAL OPERATION, INSTRUMENT MUST BE CONNECTED TO 3-WIRE GROUNDED OUTLET. BUILT-IN BATTERY WILL OPERATE INSTRUMENT FOR A LIMITED TIME ONLY.

INFUSION PUMP FLOW RATE CONVERSION CHART

SETTINGS IN DROPS PER MINUTE

ml PER HOUR	GROUP I SOLUTIONS ELECTROLYTE 5%-10% DEXTROSE						GROUP II SOLUTIONS HYPERALIMENTATION 20%-25% DEXTROSE						GROUP III SOLUTIONS ALCOHOL					
	IVAC	TRAVENOL	McGAW	ABBOTT	CUTTER	PEDS SET	IVAC	TRAVENOL	McGAW	ABBOTT	CUTTER	PEDS SET	IVAC	TRAVENOL	McGAW	ABBOTT	CUTTER	PEDS SET
5	2	1	1	2	2	5	2	1	2	1	2	5	2	1	2	2	2	5
10	3	2	3	3	4	10	3	2	3	2	4	10	3	2	3	4	5	12
15	5	3	4	4	6	15	5	3	4	4	7	15	4	4	5	6	8	17
20	6	4	6	6	8	20	7	4	6	6	9	21	7	5	7	7	10	25
25	8	5	7	7	10	25	8	5	7	7	11	26	10	6	9	9	12	32
30	9	6	9	9	12	30	10	6	9	9	13	31	12	7	10	10	15	37
35	11	7	10	10	13	35	12	7	11	10	15	36	13	8	12	12	17	39
40	12	8	12	11	15	40	13	8	12	11	17	42	15	10	13	14	20	50
45	14	9	13	13	17	45	15	9	14	12	19	47	18	11	15	16	22	56
50	15	10	14	14	19	50	17	10	15	15	21	52	20	12	17	18	25	63
55	17	11	16	16	21	55	18	11	17	17	23	57	21	13	19	20	27	69
60	19	12	17	17	23	60	20	12	18	16	25	62	22	15	20	21	30	75
65	21	13	19	18	25	65	22	14	20	20	27	67	25	17	22	23	32	81
70	23	14	20	20	27	70	24	15	21	22	30	72	27	18	24	24	34	86
75	24	15	22	21	29	75	25	16	23	23	32	78	29	19	25	26	37	94
80	26	16	23	22	30	80	27	17	24	25	35	82	31	20	27	28	39	99
85	27	17	25	23	33	85	29	18	26	26	37	88	32	21	29	30	42	
90	29	18	26	25	35	90	31	19	27	28	39	93	34	22	31	31	44	
95	30	19	27	27	36	95	32	20	28	29	41	98	36	24	32	33	46	
100	32	20	28	28	39	99	34	21	30	31	43		37	25	34	35	49	
105	33	21	29	29	40		35	22	31	32	44		38	26	35	36	51	
110	34	22	30	31	43		37	23	33	33	46		40	27	37	37	54	
115	36	23	32	32	45		39	24	34	34	48		43	28	38	39	56	
120	37	24	34	33	46		40	25	36	36	50		43	30	41	41	59	
125	39	25	35	35	48		42	27	38	37	52		45	31	42	42	61	
130	41	26	37	36	50		43	28	40	39	54		47	33	44	44	64	
135	42	27	38	38	52		45	29	42	41	56		50	34	46	46	65	
140	43	28	39	39	54		47	30	44	42	58		52	35	48	47	67	
145	44	29	41	40	55		48	31	45	44	60		54	36	49	49	68	
150	46	30	43	42	58		50	32	47	46	62		56	37	52	51	69	
155	48	31	44	43	59		51	33	48	47	64		59	39	55	52	72	
160	49	32	46	44	60		53	34	49	48	66		61	40	56	54	74	
165	51	33	47	46	62		54	35	51	50	68		62	41	58	56	77	
170	53	34	48	47	64		56	36	53	52	70		64	42	61	57	78	
175	54	35	49	48	65		57	37	54	53	72		66	44	62	59	80	
180	55	36	51	50	66		59	38	56	55	73		68	45	63	61	81	
185	57	37	52	51	67		60	39	57	57	75		69	46	65	62	82	
190	58	38	53	53	69		62	40	59	59	77		71	47	66	64	83	
195	59	39	55	54	70		63	41	60	60	79		73	49	68	66	84	
200	61	40	56	56	71		64	42	61	61	81		75	50	69	67	85	

APPROXIMATE SET RATING:

IVAC — 20 DROPS PER ml

TRAVENOL — 10 DROPS PER ml

McGAW — 15 DROPS PER ml

ABBOTT — 15 DROPS PER ml

CUTTER — 20 DROPS PER ml

PEDS (ALL) — 60 DROPS PER ml

Fig. 12—Infusion pump flow rate conversion chart for the IVAC 530. The delivered volume is dependent on the brand (size) of drip chamber and the pump rate. (Weaver LK, courtesy of J.B. Lippincott.)

which i.v. lines can be capped off and which lines are to continue during the HBO_2 treatment. These decisions need to be individualized for each patient through discussions with the patient's nurse. Another method to deal with this problem is to run compatible medications in the same i.v. line (i.e., piggyback)

14. A suction system for the monoplace chamber has been developed (25). (Drager also offers a suction unit with their monoplace chamber.) An Ohmeda vacuum regulator and suction canister are mounted in

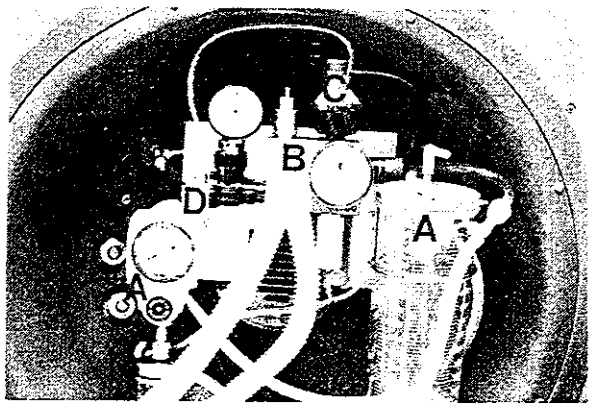


FIG. 13—Configuration of the suction assembly (A) *and Sechrist 500A ventilator* (B) *when used simultaneously (24). A Bird micronebulizer* (C) *has replaced the standard Bird 500-ml nebulizer. The vacuum hose of the Ohmeda unit runs behind the assembly and exits the chamber via a Cobe pass-through* (D).

the chamber hatch (Fig. 13). The vacuum hose that drives the regulator is passed out of the chamber via an i.v. pass-through (no. 041-600-500, Cobe) or via a specialized port because i.v. pass-throughs are occasionally in high priority. The pressurized chamber provides the gradient of pressure necessary to operate the vacuum regulator. The regulator should **NEVER** be turned to "Full" but rather to the "Regulate" position. A screw serving as a stop will prevent turning the vacuum regulator to the "Full" position (Fig. 14). The degree of vacuum can be adjusted outside the chamber by carefully positioning the handle of the three-way stopcock and reading the degree of vacuum from the regulator gauge. This system allows naso-

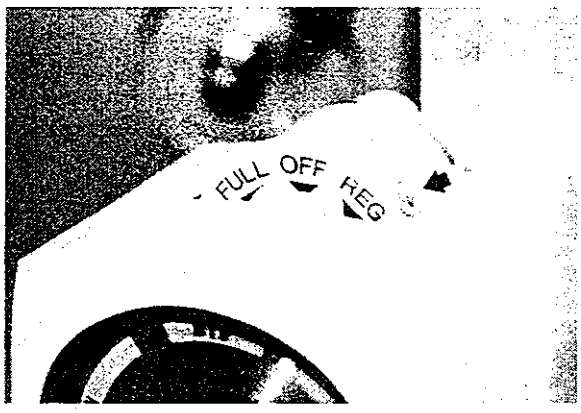


Fig. 14—Screw (arrow) *placed into the Ohmeda vacuum on-off control for a safety feature that prevents the regulator from being turned to "Full" on (24).*

gastric, oral, wound, or pleural suction during HBO_2 therapy. This system should **not** be used for endotracheal suction as there is a potential for complications (effects of auto-PEEP, reduced alveolar ventilation, or hypoxemia if inadvertently left on). Chest tubes should have a Heimlich valve or waterseal in place even with suction, in case the suction unit fails or is not turned to the "On" setting. Slow decompression rates in patients with chest tubes are recommended to allow adequate venting of any intrapleural gas that is present.

Caveats of Treating Critically Ill Patients in a Monoplace Chamber

1. Some patients, particularly those who are hemodynamically unstable, may have bradydysrhythmias during compression. This is probably due to an increase in vascular tone, which results in a reflex bradycardia. Transient complete heart block associated with hypotension and a junctional escape rhythm that occurred only a few minutes after reaching 2.4 atm abs (patient mechanically ventilated with 100% O_2) have been observed (LKW). Management required emergency decompression, i.v. epinephrine, and an increase in dopamine which restored a normal rhythm and elevated the BP. Once stabilized, the decision to resume HBO_2 therapy can be reconsidered. In this particular case, HBO_2 was resumed a few hours later without adverse sequelae.

2. Another patient (25-yr-old male with CO poisoning, aspiration pneumonia, bronchospasm, cerebral edema by CT scan, intubated, and mechanically ventilated) had been previously treated with one HBO_2 treatment (2.9 atm abs – 100% O_2 × 23 min, 5 min air, 23 min O_2; 2.0 atm abs O_2 × 46 min) (maximum chamber pressure at our elevation [1,500 m]). His cardiac rhythm went from sinus to asystole while breathing O_2 at 2.9 atm abs. The patient was emergently decompressed. By the time he was surfaced (60 s) he had a transient (15 s) electromechanical dissociation (arterial pressures were being followed continuously). As he was pulled onto the stretcher his sinus rhythm returned and he was normotensive. No drugs or electricity were used in this case. The patient received further HBO_2 treatments but was pretreated with 0.6 mg i.v. atropine. No further cardiac sequelae occurred. (He did suffer a pneumo-mediastinum presumably secondary to the rapid de-compression).

3. I have treated two septic patients (one a 9-yr-old

male with clostridial sepsis on dopamine, and the other a 22-yr-old female with a perineal necrotizing fasciitis on dobutamine) who both became hypotensive and tachycardiac following each HBO_2 treatment. Volume loading of septic patients toward the end of the HBO_2 treatment with blood, fresh frozen plasma, or albumin should be remembered to alleviate the post-HBO_2 hypotension.

Summary

This section of the Monoplace Chamber Safety Manual has focused on patient monitoring and life support in the monoplace hyperbaric chamber. It is not my intent to encourage critically ill patients to be placed in monoplace chambers indiscriminately and with impunity, but rather to provide information about facets of monitoring and life support that are important in treating patients in the monoplace chamber. I cannot emphasize enough that the successful management of difficult and critically ill patients in the monoplace chamber rests on a well-trained and dedicated staff who operate the chamber. As with any patient, and especially for the critically ill patient, the question of risk vs. potential benefit of treating with HBO_2 must be constantly evaluated.

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CHAPTER VII: SYSTEM AND MAINTENANCE

Judy Johnson

Cleaning of the Chamber

1. All mechanisms must be kept clean and in optimal working condition at all times. The main inlet filter should be replaced on a yearly basis. The regulators, flow computer, and exhaust system must be kept clean and free of lint and foreign debris. The manufacturers recommend factory-approved preventive maintenance and repairs.

2. Care should be exercised in cleaning the acrylic cylinders to prevent abrasion and/or damage. Always use a water-moistened, soft, lint-free cloth to remove dust. Never allow any liquids or solvents to come in contact with the acrylic cylinder other than mild soap and water or a diluted solution of Huntington Labs HI-TOR "A". Do not allow water to accumulate in the bottom of the chamber cylinder because it could possibly drain into the supply and exhaust piping system. If crazing or deep scratches appear on the acrylic surface, immediately contact the chamber manufacturer.

3. Always keep the chamber covered and the chamber door closed when not in use. Do not store items near the chamber if there is a possibility that anything may fall on or against the chamber. Hospital housekeeping should be allowed to clean the chamber room only. Hyperbaric personnel should clean the chamber. Do not allow unauthorized personnel in the chamber area during use or non-use. The chamber room should be kept locked when not in use.

Lubricants

1. Petroleum-based dressings should be minimized on patients undergoing hyperbaric treatment. If petroleum jelly gauze dressings are used, they must be covered with a cotton dressing (*see* chapter VIII).

2. Only oxygen-compatible, fluorinated greases are acceptable. Krytox GPL 205 (E.I. DuPont De Nemours, Wilmington, DE) is one such product.

Inspections

1. Follow all manufacturer's recommendations for periodic inspections in the chamber operations manual.

2. Yearly calibrations of the chamber pressure regulators should be done by the manufacturer or a calibration service.

Safety, Maintenance, and Repair

1. Regular maintenance on the monoplace chamber is necessary. Manufacturers recommend factory authorized preventive maintenance on a yearly basis. All repairs must be done by qualified repairmen.

2. The life span of an acrylic cylinder is 10 yr or 10,000 cycles. At this time the chamber should be returned to the manufacturer for a complete factory overhaul.

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READER'S NOTES

CHAPTER VIII: PATIENT PREPARATIONS

Michael B. Strauss, M.D.

Introduction

1. Patient preparations for hyperbaric oxygen (HBO_2) treatments require orientation, informed conent, physical preparation, and in some cases intervention from specialists.

2. Without appropriate preparations, patients may be unwilling to have HBO_2 treatments or their non-HBO_2 care may be compromised.

3. Patient preparations must be done efficiently to start HBO_2 treatment as soon as possible. This is especially important in conditions where HBO_2 is emergent, such as in diving accidents, carbon monoxide poisoning, threatened flaps, reperfusion injury, and *Clostridial myonecrosis*. Conversely, patient preparations must be done thoroughly so as not to compromise the patient's medical and nursing care or place the patient at an unacceptable risk during the HBO_2 treatment.

Orientation

1. Orientation to HBO_2 treatment needs to be done in a systematic, stepwise process to be complete, efficient, and not omit essential components.

2. In general, the orientation should be done in a two-fold fashion. The attending HBO_2 physician should introduce the subject of HBO_2 to the patient. This should include:

a. Mechanisms of HBO_2 that apply to the patient's condition for which HBO_2 is indicated. Alternatives to HBO_2 treatments and the consequences of not having HBO_2 should be discussed.

b. Risks and possible side effects of HBO_2 including oxygen toxicity, barotrauma, visual changes, and confinement anxiety.

c. Measures used to reduce the chances of a side effect from HBO_2, as well as how a side effect, should it occur, is managed.

d. Review of patient's medical history, medications, and habits.

- Special notation must be made of a seizure disorder and whether the patient is taking anticonvulsant medications. If the patient is receiving an anticonvulsant drug, tests to determine if the medication is at a therapeutic level should be obtained.
- If the patient smokes, he/she should be informed of the need to stop during the course of HBO_2 treatments, and why smoking interferes with the effectiveness of HBO_2.
- Certain medications such as aspirin, nitroprusside, and i.v. lipids may increase the risk of toxicity from HBO_2. Ideally they should be temporarily interrupted during the actual HBO_2 treatments to lessen the chances of seizures, hypotension, and pulmonary oxygen toxicity.
- Ascertain that there are no absolute or relative contraindications to HBO_2.

e. Physical assessment of the patient including vital signs and conditions for which HBO_2 is indicated. If the patient is febrile or acidotic, correcting these conditions will lessen the chance of a seizure.

f. Determining the requirement of i.v. lines and other special equipment for the patient during the HBO_2 treatment is necessary.

g. Summary of the treatment schedule, treatment duration, and anticipated benefits from HBO_2.

3. The second component of the orientation process is performed by the hyperbaric specialist (i.e. registered nurse, respiratory therapist, hyperbaric technician). It should compliment and expand the physician's orientation. This portion should emphasize safety precautions with HBO_2 and how the patient's concurrent interventions, e.g., ECG, i.v. lines, etc., will be continued during the HBO_2 treatment. Additional considerations for this phase of the orientation include:

a. Review of substances that are not allowed on the

patient during the monoplace hyperbaric treatment including hair oils, wigs, skin lotions, dressings with oil bases, exposed metal objects, and gowns with synthetic fibers, watches, hearing aids, any items of street clothing, or other objects not related to hyperbaric treatment.

b. Methods to avoid middle ear barotrauma are taught. The patient is informed of the symptoms of middle ear barotrauma and how to inform the chamber operator of such. The patient is told that further pressurization of the chamber will be stopped until middle ear pressure equilibration is achieved when symptoms of barotrauma occur. A positive history of middle ear barotrauma with pressure changes (e.g., with flying) may indicate the need for prophylactic decongestants and/or tympanotomy tubes.
c. Techniques to reduce anxiety during HBO_2 treatments such as relaxation techniques may be taught.
d. Schedule treatments to avoid interference with the patient's other care. If the patient is diabetic the HBO_2 treatments should not interfere with meals or insulin administration. The HBO_2 treatment should not put the patient in jeopardy of becoming hypoglycemic.

4. Orientation of children, especially those less than 7 yr of age is compromised by the patient's level of comprehension. Some children are able to clear their ears naturally by swallowing or sucking on a bottle or through a straw while being pressurized. Since treatment schedules in children are generally shortened, anxiety and boredom is less apparent. Appropriate sedation can be used for the active child. Naturally, the child's parents should be informed of all the information given to the adult patient.

5. Orientation of the unconscious patient is limited. The legal next of kin should be given the orientation procedures. Myringotomies are suggested for intubated patients (*see* chapter VI).

6. Writing and signing the baromedical orders completes the orientation process. The orders should include but not be limited to the following items:

a. HBO_2 treatment schedule (pressure, duration, frequency, and air breaks, if used).
b. Signed consent after appropriate orientation.
c. Clinical photos if wounds are involved.
d. Systemic vasoconstrictors (with or without antihistamines) and/or local vasoconstrictors for prophylaxis against middle ear barotrauma Chronic use of nasal sprays before tretment is not recommended.
e. Vitamin E, 400 mg twice a day if patient is taking food by mouth, for its antioxidant (seizure reducing) effect. Use of this prophylactic measure is a matter of physician's choice.
f. Intravenous rates, ventilator settings, and cardiac monitoring, if necessary.
g. Soft restraints if patient has an altered or vacillating level of consciousness.
h. No smoking.
i. Cessation of i.v. intralipids (usually given with hyperalimentation) 4 h before the scheduled HBO_2 treatment. [*Editor's comment*: There are no data in humans that concurrent administration of lipids during HBO_2 potentiates O_2 toxicity, but based on animal data and theoretical grounds, this recommendation is reasonable.]
j. Consider weekly complete blood counts if patient is given HBO_2 treatments to continue for more than a week. This test monitors anemia which may be associated with HBO_2.
k. Sedative or minor tranquilizer medications to counteract confinement anxiety on an "as needed" basis.
l. Consider timing aminoglycoside antibiotics to occur before HBO_2 to enhance aminoglycoside-related killing of bacterial cells, which is an O_2-dependent process (1).

Informed Consent

1. Before initiating HBO_2 treatment, informed consent must be obtained. Since the legal application of the doctrine of informed consent varies considerably from state to state, it is advisable to consult local state laws for its specific requirements for content and responsibility. If the patient is unable to sign his own consent because of intervening physical or mental conditions, a signed consent from the patient's next of kin is acceptable. When neither of these methods of obtaining an informed consent is feasible, then two physician's signatures in the medical record, with an explanation why the patient is unable to sign, suffices. Consents obtained via a telephone call with the patient's next of kin are acceptable if witnessed

(e.g., heard on the phone) by a third party.

2. The consent process requires an approximate orientation as discussed in the previous section. However, the written consent need not include all the items and details given in the orientation. For record-keeping purposes and to satisfy medical requirements, the written consent should include:

a. Consent for HBO_2 treatments.
b. Acknowledgment of inherent risks or complications of HBO_2 in lay terms.

Physical Preparations

1. Physical preparations of the patient for HBO_2 vary from merely having the patient change from street clothes to a cotton gown to complex transport and monitoring adaptations.

2. Ambulatory patients need minimal preparations. They are required to change into the standard (non-static) cotton gown. Vital signs are recorded. Otoscopic exams are performed before and after each HBO_2 session. Cerumen may be removed by lavage techniques. Jewelry, watches, and other metallic objects are removed. The patient is given the opportunity to sleep, read (with the reading material outside of and on top of the chamber acrylic), watch television, or listen to the radio or recorded music.

3. For alert patients who are medically stable, but nonambulatory, transportation from their room to the hyperbaric chamber is done on the hyperbaric gurney. The patient must be appropriately strapped to the gurney or have side rails raised. Measures as for the ambulatory patient are performed but are supplemented with the following if applicable:

a. Intravenous pass-throughs are connected, or if the patient has an i.v. for keep open purposes (intermittent administration of medications) it may be heparin locked.
b. If diabetic, the patient's pretreatment blood sugar is noted and if low the patient is given oral nourishment or i.v. glucose is infused.
c. Bladder and nasogastric (NG) drainage bags are emptied. Suction may be applied to NG tubes (*see* chapter VI).
d. Suction-irrigation devices for wound healing are checked to be sure they are sealed, and cleared of air (i.e., the Hemovak reservoir is collapsed).
e. Dressings are checked and if leakage is observed the dressings are reinforced.
f. Metal objects such as exposed pins or external fixators are covered or wrapped with cotton towels to prevent damage to acrylic cylinder of the monoplace chamber.
g. Set up and monitoring of transcutaneous O_2 levels if the device is appropriately adapted for the monoplace chamber (*see* chapter VI).

4. Critically ill patients require additional physical preparations for HBO_2. The preparations previously described if applicable to the patient are done, but additional considerations include:

a. Respiratory therapist to accompany and ventilate patient from the intensive care unit to the hyperbaric chamber. Intubation cuffs are filled with normal saline.
b. Conversion of chest tube drainage devices to Heimlich valves if continuous suction is not provided in the chamber.
c. Restraint of the unconscious or nonresponsive patient during the HBO_2 treatment. Consider bilateral myringotomies.
d. Establish respiratory arterial line and pulmonary arterial monitoring if needed during the HBO_2 treatment.
e. Provide and connect i.v. pumps for infusions during HBO_2 treatment.
f. Set up blood pressure monitor if cuff device is to be used.
g. Appropriately transfer the spinal cord injured patient to the HBO_2 traction apparatus (Sukoff device) (2). The transfer should be done with a physician in attendance. Ordered settings for cervical traction are to be verified and checked periodically during the treatment.

5. The more acutely ill the patient is, the more preparation is needed. Physician attendance is not required at all HBO_2 treatments. However, a physician should always be readily available for consultation purposes. It is recommended that a physician be present for HBO_2 treatments when the patient is hemodynamically unstable or likely to experience problems during the transition from the completion of the HBO_2 treatment to the transfer to the intensive care unit. This is a particularly vulnerable time for the septic patient who is hypovolemic and/or anemic. When treating acutely ill patients it is recommended that critical-care-trained nurses be present for physio-

logic monitoring and critical care nursing.

Special Interventions

Rarely is the patient unable to have HBO_2 treatments because of intervening physical and/or mental conditions. In some situations, special interventions by consultants can remedy the problem. For example:

1. Occasionally, patients with arteriosclerotic cardiovascular disease complain of dyspnea during the HBO_2 treatment. A careful history usually discloses the presence of orthopnea. Because of concerns about borderline renal function in this group of patients it is desirable to have a cardiologist or nephrologist monitor the diuresis. Use of sedatives is not the appropriate management for this problem. However, if the patient becomes fearful of the HBO_2 treatment after the problem is corrected, sedatives and/or psychiatric assistance may be necessary.

2. Rarely are patients unable to equilibrate pressure in their middle ear spaces even when clearing techniques and medications are used. Otolaryngologic consultation for myringotomies or operative placement of ventilation tubes will make it possible for the patient to continue HBO_2 treatments.

3. A small number of patients morbidly fear HBO_2 treatments. Interventions by psychiatrists are helpful. Generally psychotherapy and the adjunctive use of minor tranquilizers is sufficient to control the patient's fears of HBO_2. Reducing treatment duration and increasing treatment frequency often compliments psychiatric intervention.

4. Controversy exists as to whether all patients who receive HBO_2 should have pre- and posttreatment visual exams (3). Transient HBO_2-induced myopia (i.e., nearsightedness) is occasionally observed in patients who receive over 20 treatments and is considered a known side effect (4). Hence, any other visual change or nearsightedness developing after only a few HBO_2 treatments requires immediate ophthalmologic consultation before additional HBO_2 treatments are given. Prolonged HBO_2 can accelerate the growth of preexisting cataracts (5).

5. Hyperbaric oxygen treatments are rarely requested for neonates for septic conditions, burns, CO poisoning, etc. (6). Before HBO_2 is started, an opinion by the neonatologist is needed to rule out prematurity and the possibility of retrolental fibroplasia developing. Because of the smaller body mass and increased metabolic rate, shorter treatments (30 min), increased frequencies (3–4 times a day), and lower pressures (1.5 atm abs) should be considered.

6. Although pregnancy is considered a relative contraindication for using HBO_2, it is recommended for those patients who are victims of carbon monoxide poisoning (7) or scuba diving accidents.

Summary

Patient preparations are an essential component of HBO_2 safety procedures. In most circumstances they are expediently done. Guidelines and check-off lists modified for each HBO_2 facility are recommended for the unit's procedures and protocols manual. No patient should be treated without an informed consent and appropriate orientation. If consent is unobtainable from the patient in case of an emergency, the legal state doctrine should be followed. In a nonemergent situation in which appropriate consent cannot be obtained, a legal guardian or conservator must give consent according to local state doctrines.

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CHAPTER IX: ADMINISTRATION AND RECORDS

Valerie Messina, R.N.

Introduction

1. The administration of a hyperbaric medicine department varies from institution to institution. Generally, a hyperbaric medicine department is administered as a special care unit or ancillary service within a hospital or medical center and must meet the criteria of that institution. If the organization seeks accreditation from the Joint Commission on Accreditation of Health Organizations (JCAHO).

2. The hyperbaric medicine department is directed by a qualified physician member of the medical staff. The supervision of nursing care is provided by a designated qualified nurse. Generally, a department is administered by a designated and qualified manager or department head. Department personnel are prepared for their responsi-bilities in a hyperbaric department through appropriate training orientation, in-service training, and continuing education programs.

3. The provision of care is guided by written policies and procedures developed by the medical staff and the nursing service. They are revised as necessary and reviewed according to institution policy. Policies and procedures should include administrative, patient care, and departmental operations. Specific policies and procedures need to be in compliance with JCAHO if accreditation is sought.

4. The department must have an ongoing quality assurance (QA) program to monitor the quality and appropriateness of the patient care provided in the department. Generally, the program is designed to meet current JCAHO criteria and is multifaceted. The medical director is responsible to the hospital medical QA committees to evaluate the quality and appropriateness of care. The department head is responsible for administrative QA requirements, and medical director of facility is responsible for clinical monitoring. Standards of care, standards of performance, and standards of practice are monitored.

a. An example of a medical indicator is the rate of complications resulting from hyperbaric treatment or the appropriateness of patient referrals for HBO_2 treatment.

b. An example of administrative QA monitoring is timeliness of response to immediate (STAT) orders or patient satisfaction.

c. Examples of nursing QA monitoring are structural, process, and outcome standards.

5. Quality assurance monitoring should reflect the current guidelines of JCAHO, which are updated annually.

Records

1. In addition to the departmental records of policies and procedures and staffing schedules, documentation of the medical and nursing care and treatment delivered must be made. Departmental records should be maintained per organizational policy and JCAHO requirements.

2. Patient care.

a. Treatments must be logged in a departmental document including equipment used, time, and treatment protocol.

b. Treatment records should include pretreatment assessment, treatment protocol, and interventions and posttreatment assessments. These become a permanent part of the patient's medical record and must meet approval of the institution's forms committee.

c. Documentation of care is entered in the patient's medical record and is integrated with the health team progress notes. This includes the initial physician consultation and orders, progress notes, and discharge summaries.

3. Records must be maintained as dictated by the institution's policies. Generally, these include maintenance records, gas purity and analysis monitoring, staffing schedules, and treatment schedules. Storage of records for a 7-yr period is recommended.

READER'S NOTES

APPENDIX A

The American Society of Mechanical Engineers
United Engineering Center
345 East 47th Street
New York, NY 10017

Joint Commission on the Accreditation of Health Organizations
875 North Michigan Avenue
Chicago, IL 60611
312/642-6061

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

APPENDIX B

Compressed Gas Association (CGA)
1235 Jefferson Davis Hwy.
Arlington, VA 22202
703-979-0900

1. For 75 years the CGA has developed and revised standards for the safe handling of compressed gases.
2. CGA standards are published in a variety of forms, the most comprehensive being the *Handbook of Compressed Gases* (1989). This publication contains all inclusive information on every aspect of handling gases in compressed, liquid, and solid form.
3. Eight audiovisuals are available, of which three are of particular interest to those involved in the provision of hyperbaric oxygen therapy:

   AV-1 Safe Handling and Storage of Compressed Gases
   AV-4 Characteristics and Safe Handling of Medical Gases
   AV-8 Characteristics and Safe Handling of Cryogenic Liquid and Gaseous Oxygen

4. Technical publications in the form of pamphlets suitable for compilation within a three-ring binder are divided into nine sections, with section titles and recommended reading for hyperbaric personnel listed below.

4-1. Cylinders

C-4 American National Standards Institute (ANSI) Method of Marking Portable Compressed Gas Containers to Identify the Material Contained (1978)
C-7 Guide to the Preparation of Precautionary Labeling and Marking of Compressed Gas Cylinders (1983)
C-9 Standard Color Marking of Compressed Gas Cylinders Intended for Medical Use (1988)

4-2. Regulators and Hose Line Equipment

E-3 Pipeline Regulator Inlet Connection Standards (1981)
E-7 Standard for Flow Meters, Pressure Reducing Regulators, Regulator/Flow Meter and Regulator/Flow Gauge Combinations for the Administration of Medical Gases (1983)

4-3. Gases

G-4 Oxygen (1987)
G-4.1 Cleaning Equipment for Oxygen Service (1985)
G-4.3 Commodity Specification for Oxygen (1980)
G-4.4 Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems (1980)
G-4.5 Commodity Specification for Oxygen Produced by Chemical Reaction (1983)
G-7 Compressed Air for Human Respiration (1976)
G-7.1 Commodity Specification for Air (1973)

4-4. Protection and Safe Handling

P-1 Safe Handling of Compressed Gases in Containers (1984)
P-2 Characteristics and Safe Handling of Medical Gases (1978)
P-2.5 Transfilling of High Pressure Gaseous Oxygen to be used for Respiration (1987)
P-2.6 Transfilling of Liquid Oxygen to be Used for Respiration (1983)
P-6 Standard Density Data, Atmospheric Gases and Hydrogen (1985)
P-11 Metric Practice Guide for the Compressed Gas Industry (1980)
P-12 Safe Handling of Cryogenic Liquids (1987)
P-14 Accident Prevention in Oxygen-Rich and Oxygen-Deficient Atmospheres (1983)

4-5. Pressure Relief Devices

S-1.1 Pressure Relief Device Standards, Part 1: Cylinders for Compressed Gases (1979)
S-1.3 Pressure Relief Device Standards, Part 3:
Compressed Gas Storage Containers (1980)

4-6. CGA Safety Bulletins:

SB-2 Oxygen-Deficient Atmospheres (1983)
SB-7 Rupture of Oxygen Cylinders in the Diving Industry (1980)
SB-10 Correct Labeling and Proper Fittings on Cylinders/Containers (1985)
TB-3 Hose Line Flashback Arrestors (1983)

4-7. Valve Connections

V-1 ANSI, Canadian, CGA Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections (1987)
V-5 Diameter Index Safety System (1978)

4-8. Insulated Cargo Tanks

4-9. Cylinder Ownership Symbol Registration Program

GLOSSARY

American National Standards Institute	ANSI
American Society of Mechanical Engineers	ASME
Compressed Gas Association	CGA
Joint Commission on the Accreditation of Health Organizations	JCAHO
National Fire Prevention Association	NFPA
Pressure Vessels for Human Occupancy	PVHO

READER'S NOTES

MONOPLACE HYPERBARIC CHAMBER SAFETY GUIDELINES
FOR UHMS
EDITORS: LINDELL WEAVER & MICHAEL STRAUSS
REVISED 1997

The manual provides a good overview of the most salient aspects of monoplace chamber operation.

The following key facts are included that deserve special mention and consideration.

CHAPTER 1: INTRODUCTION : MICHAEL STRAUSS

The first prototype monoplace hyperbaric chamber was installed at Westminster Hospital, England in 1964. This model was eventually copied by the USSR where it became the most popular monoplace design.

Collapsible hyperbaric chambers were fitted to ambulances already in 1963 for the treatment of carbon monoxide and myocardial infarction.

Seven monoplace hyperbaric chamber fires have occurred in China from 1967 to 1996. Four have occurred in Japan (all the result of pocket warmers).

There are an estimated 5000 monoplace units in service throughout the world.

CHAPTER II: CONFIGURATION AND ADAPTATIONS TO THE MONOPLACE CHAMBER: GEORGE HART

Monoplace chambers require hydrocarbon filters in air lines as well as 1u filters for calcite cristals formed by the water-based lubricants used in teflon ring compressors.

Oxygen lines should also be filtered to avoid entrained debris causing malfunction of the monoplace chamber controls.

Special trays have been devised for patients with cervical spine fractures that allow in-line traction in the monoplace (Sukoff).

Decompression from a monoplace chamber should be possible in 90 seconds.

CHAPTER III: REGULATIONS FOR MONOPLACE CHAMBERS: DICK CLARKE

Defibrillation and other electrical devices should be performed/ positioned at least 6-8 feet (2.44 meters) from the open door of the chamber.

Best artificial lighting are reostat controlled incandescent lights. Flourescent lights emit red(?) UV

light that may degrade the acrylic and flickering may induce O2 toxicity seizures.

27 degrees centigrade and >50% relative humidity is recommended for the internal chamber environment.

Waxes and polishes that may be entrained in the chamber by mechanical transfer or may interfere in the conductivity of flooring should be avoided.

Perry Sigma I chambers do not have a double tube acrylic tube, but an outer sheet of acrylic wrapped around the tube and a slightly thicker inner tube.

Spare o-rings and gasket seals are recommended in case of leaks.

Ground fault interruption (GFI) is recommended for all supplies to electrical systems related to a monoplace chamber as well as any devices used in association with the chamber, e.g. TV, ECG, etc. Full loading GFI should be rated 2x the maximum anticipated requirement for the equipment used. Chamber grounding is recommended by means of 6 AWG braided copper cable to earth.

Chamber comms output voltage should be less than 5 V (is this outdated).

Patient grounding is recommended to dissipate static generated through movement.

CHAPTER IV: MONOPLACE HYPERBARIC FACILITY: JUDY JOHNSON

Chamber orientation should always allow immediate egress from the chamber. Consequently two chambers may not be positioned at angles that would impair simultaneous evacuation.

Conductive flooring not required for monoplace facilities.

The rest of the chapter overlaps largely with Dick Clarke's chapter.

CHAPTER V: GAS SUPPLY AND EXHAUST SYSTEMS: JIM MCCARTHY

Oxygen liquid to gas conversion factor: 860:1 @STP

Vickers chamber:
Floodable volume: 18.4 cubic feet (520.72 liters)
Requires additional 36.8 cf (1041.44 liters) to compress to 3 ata.
Ventilation rates vary between 240 and 400 lpm
Typical oxygen usage:

- 1041.44 for compression
- 240-400 lpm x treatment duration (60 - 90 min)
- "No" additional use during decompression

Pipe diameter: for 727 lpm flow, 3/4 inch (19 mm) oxygen piping is required.
Chamber line pressures:

- 3.75-4.1 kg/cm2 (no ventilator)
- 4.75-5.1 kg/cm2 (with other oxygen consuming equipment and ventilator)
- Ventilator supply pressure: 4.1-5.45 kg/cm2

In-line oxygen filter recommended: 5u @ 858 lpm flow
Flexible hose ratings: 27.5 kg/cm2
Exhaust pipes fitted with double inverted elbows with screening.
Rigid exhaust piping should extend into room at least7.62 cm.
Chamber exhaust pipe diameter:
No change in diameter up to 4.57 meters
If longer, double (cross section) surface area

Oxygen to air switch during Rx takes approximately 15 minutes (for seizure management)
In line oxygen analysis required if double supply is provided.

CGA medical air standards table provided on page 22.

Compressor inlet: Inlet doubled for every 3.3 meters between inlet filter and first stage.

Catalytic CO-converter could be used to avoid CO contamination (Deltech Engineering).

CHAPTER VI: MONITORING & LIFE SUPPORT: LINDELL WEAVER:

Patient grounding recommended.

Draeger has an electronic stethospcope for NIBP, using radial artery and pneumatic inflation via oxygen line (I believe that these devices were originally attached to the Vickers Chambers. They may be somwhat cheaper than the Oscillomate). Page 25-26.

Arterial Line measurement components:
Tycos Pressure Infuser.
Intraflow transducer flusher or IV setup.
Transpac transducer (notch for chamber pressure sampling must be provided for Transpac) or Cobe vented Transducer.

Radiometer ABG 330 can accurately measure hyperbaric arterial blood gas.

POET EtCO2 side-stream monitor effective for capnography. Nasal cannula used for sampling breathing patients.

Hans Rudolph two-way non rebreathing valve sampling more accurate.

Four penetrator split bolt may be a less expensive alternative to Sechrest pass-throughs for IV lines.

Elaborate techniques on arterial blood sampling, ventilator settings and Scwann-Ganz catheter use is included.

Only one recorded case of pulmonary barotrauma with death by AGE is recorded by the author in a routine HBO in a patient with significant pulmonary parenchymal disease and fibrosis.

Volume loading of septic patients before decompression is strongly recommended as they may deteriorate post treatment.

Suction devices (e.g. Ohmeda suction regulator) must be prevented (by a screw) from being turned to "Full" setting.

Note bradyarhythmias in HBO patients: Either increase adrenaline or prevent with atropine.

CHAPTER VII: SYSTEM AND MAINTENANCE: JUDY JOHNSON

Main inlet filter replaced annually.

HiTor antiseptic of choice.

Chamber covered and door closed when not in use.

Petroleum-based dressings avoided and covered with cotton.

Oxygen compatible lubricants only.

Follow-manufacturers recommendations for chamber service.

Replace acrylic tube after 10 years of 10 000 cycles.

CHAPTER VIII: PATIENT PREPARATION: MICHAEL STRAUSS

Orientation should include:

- Mechanisms of HBO
- Side-Effects & Dangers
- Measures to manage or minimise risks
- Review patient history especially in terms of:
    - Seizure disorders.
    - Smoking.
    - Medications.
    - Contraindications to HBO.

- Physical Assessment.
- Requirement for meds, monitoring or IV's.
- Nurse orientation to the chamber.
    - Unsafe objects
    - MEBT
    - Anxiety
    - Hypoglycaemia

Hyperbaric orders:

- HBO Schedule
- Signed Consent
- Photos
- MEBT prevention measures
- Vit E 400 IU
- IV, ventilator and other set-up
- Soft restraints if indicated
- Sedatives if required
- No smoking
- Weekly FBC's
- Medications: Toxicity or synergy with HBO

Note: Clear Portovacs of air.

CHAPTER IX: ADMINISTRATION & RECORDS: VALERY MESSINA

Administration as determined by JACHO

HBO MD, Nurse and Adminstrator

QA plan:
Medical Quality: Number of complications and appropriateness of referrals
Nursing Quality: Records and Orders Implementation

Documentation:
Regular records plus:
Treatment Logs
Treatment Records
Physician Consultation; Orders; Progress Notes; Discharge Summary.

RECOMMENDATIONS & MODIFICATIONS TO CURRENT PRACTICE BASED ON THIS DOCUMENT:

1. Ensure completion of all documents before initiating treatment.
2. Review patient charts and logs weekly to complete omitted information while treatments are in progress.
3. Perform regular fire drills & cardiac arrest drills.
4. Confirm GFI rating on electrical systems.
5. Explore and provide arterial pressure measuring equipment for unit.
6. Explore the possibility of manufacturing split bolt penetrators.
7. Use methylene blue to identify line dead-space clearance.
8. Develop structures and training-aid supported orientation to HBO for new patients.
9. Determine need for oxygen in-line filter and air filtration (if teflon compressor).
10. Determine the implications of present floor cleaning-waxing practices.
11. Develop and implement protocols for various HBO related activities, e.g. glucose analysis, portovac management.
12. Provide pre-treatment patient nursing checklist: Ears, Lungs, IV's, Meds, Temp, Drains, Cuffs & Bags, Glucose (DM), Anxiety.
13. Provide post treatment checklist: Ears; Complications.