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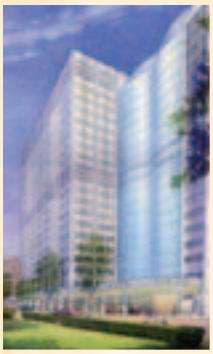

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New Hyperbaric and Altitude Medicine Program at Mayo Clinic Rochester

Raymond C. Shields, MD

In January 2008, Mayo Clinic Rochester launches a clinical and research hyperbaric and altitude medicine program. The multidisciplinary efforts of the Division of Preventive, Occupational, and Aerospace Medicine, the Division of Cardiovascular Diseases, and the Gonda Vascular Center focus primarily on the management of chronic nonhealing wounds. "This program is an important extension of the Wound Center as an additional tool in managing problem wounds, with the goal of providing comprehensive care and further improving limb salvage rates," says Raymond C. Shields, MD, Mayo Clinic Rochester cardiologist and member of the staff of the Gonda Vascular Center.

Mechanisms of Action

Hyperbaric oxygen therapy is defined as exposure to 100% oxygen at a pressure greater than atmospheric pressure. The modern clinical and scientific use of hyperbaric oxygen started in 1955 as an adjunct to cardiac surgery before the wide availability of cardiopulmonary bypass machines.

Under conditions of normal perfusion at rest, tissues extract between 5 and 6 mL of oxygen per deciliter of blood. Based on Henry's law (the partial pressure and concentration of a gas dissolved in a liquid are determined by the partial pressure of the gas on the surface of that liquid), at sea level while breathing ambient air (1 atmosphere = 1 kg/cm^2, 760 torr, or 760 mmHg), the plasma oxygen concentration is 0.3 mL/dL. At sea level, this concentration increases 5-fold to 1.5 mL/dL with administration of 100% oxygen. At 3 atmospheres of pressure, the dissolved plasma oxygen content approximates 6 mL/dL; this level allows for sufficient oxygenation of resting tissues, regardless of the oxygen-hemoglobin content. At the tissue level (muscle and subcutaneous tissue), the partial pressure of oxygen at 2 atmospheres of compression while breathing 100% oxygen approximates 300 mmHg.

Based on Boyle's law (the volume of a confined gas is inversely proportional to the pressure at a constant temperature) and Laplace's law, the primary effects of increased pressure and levels of oxygen are reduction in bubble size and bubble dissolution.

Indications and Secondary Effects

These mechanisms of action (changes in pressure and oxygenation) are particularly applicable in the urgent management of arterial gas embolism and decompression illness. Indeed, hyperbaric oxygen is the primary therapy for arterial gas embolism and decompression illness. Other important indications for hyperbaric oxygen therapy are listed in the Table.

Secondary effects of hyperbaric oxygen therapy are diverse and include the following:

1. *Increased leukocyte oxidative intracellular killing*. Leukocyte phagocytosis is improved with increased tissue oxygen levels (Po_2 of 45 to 150 mmHg) achieved with hyperbaric oxygen versus decreased tissue oxygen levels (less than 30 mmHg). Clinical applications include necrotizing soft tissue infections and chronic refractory osteomyelitis.
2. *Toxin production, inhibition, and inactivation*. Hyperbaric oxygen therapy is effective for inactivat-

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ing clostridial toxins and is directly bactericidal to *Clostridium perfringens*. This effect is applicable in the management of clostridial gas gangrene.

3. *Osteoclast stimulation*. Osteoclast function is stimulated by hyperbaric oxygen, which is elemental in the management of chronic refractory osteomyelitis and osteoradionecrosis.
4. *Fibroblast proliferation and collagen synthesis stimulation*. This process is also oxygen dependent and is important in the proliferative and remodeling stages of wound healing.
5. *Angiogenesis stimulation*. Tissue oxygen gradients generated by hyperbaric oxygen stimulate capillary formation. This is particularly applicable to graft salvage, soft tissue radionecrosis, and osteoradionecrosis.
6. *Vasoconstriction*. Vasoconstriction with hyperbaric oxygen results in tissue edema reduction while ameliorating ischemia, which is particularly important in the management of crush injuries and acute thermal burns.

Contraindications

Absolute contraindications for hyperbaric oxygen therapy include concurrent use of doxorubicin (due to possible increased cardiotoxicity). The cytotoxic effect of *cis*-platinum may be enhanced with hyperbaric oxygen therapy, thereby diminishing wound healing. Disulfiram inhibits superoxide dismutase production, the major defense against oxygen toxicity. Untreated pneumothorax is also an absolute contraindication for hyperbaric oxygen therapy.

Hyperbaric oxygen therapy has the following relative contraindications: upper respiratory infection, chronic sinusitis, seizure disorder, emphysema with CO_2 retention, heart failure, high fever, history of spontaneous pneumothorax, history of thoracic surgery, viral infection, congenital spherocytosis, and history of optic neuritis. The benefit of instituting hyperbaric oxygen therapy should be weighed against the risk of adverse reactions. Tumor growth does not appear to be stimulated by hyperbaric oxygen therapy, and pregnancy is not a contraindication for emergent indications.

Conclusions

Hyperbaric oxygen therapy administered according to standard protocols is considered safe (Figure). Middle ear "squeeze" or barotrauma is the most common complication of hyperbaric therapy. The risk of barotrauma can be minimized with appropriate screening, patient education, and monitoring. Patients who receive a prolonged course of normobaric increased FIO_2 therapy and then undergo repeated exposure to hyperbaric oxygen are at the greatest risk for pulmonary oxygen toxicity. Generalized seizures may occur in patients during hyperbaric oxygen therapy but are considered rare and self-limiting, with no subsequent neurologic sequelae reported.

Mayo Clinic Rochester has an important place in history with altitude physiology research and training dating back to 1939, preceding World War II. "Many of the currently available aircraft oxygen and antigravity systems were developed in the Mayo Clinic Aeromedical Unit," says Dr Shields. "The current hyperbaric and altitude medicine program will also include opportunities for altitude physiology training and research."

Table. Evidenced-Based Indications for Hyperbaric Oxygen Therapy

Primary Therapy	
Cerebral arterial gas embolism	Decompression illness
Adjunctive Therapy	
Selected problem wounds	Refractory osteomyelitis
Osteoradionecrosis	Necrotizing infections
Osteoradionecrosis prophylaxis	Crush injuries
Radiation tissue damage	Clostridial gangrene
Carbon monoxide poisoning	Acute thermal burns
Compromised skin grafts or flaps	Acute exceptional blood loss

Figure. Dr Shields demonstrating use of the oxygen hood used by patients during hyperbaric therapy.