Hyperbaric oxygen therapy for treatment of diabetic foot ulcers

This adjunctive therapy promotes wound healing and may eliminate the need for amputation.

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Every year, 1.9% of patients with diabetes develop foot ulcers. Of those, 15% to 20% undergo an amputation within 5 years of ulcer onset. During their lifetimes, an estimated 25% of diabetic patients develop a foot ulcer. This article discusses use of hyperbaric oxygen therapy (HBOT) in treating diabetic foot ulcers, presenting several case studies.

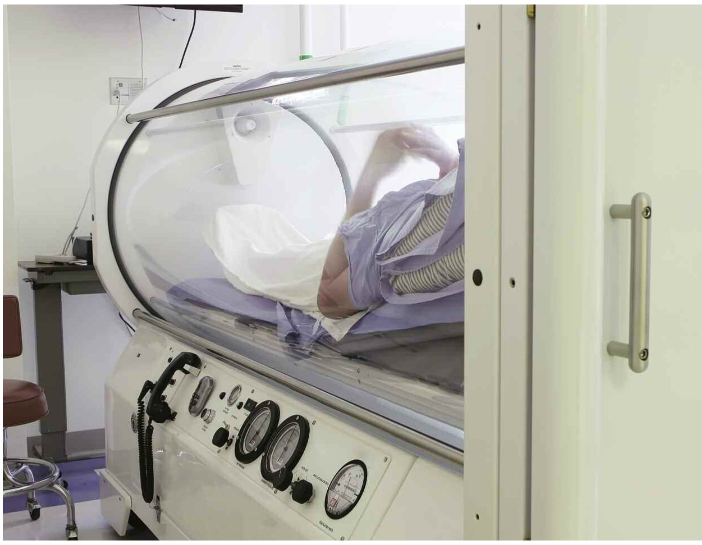
HBOT involves intermittent administration of 100% oxygen inhaled at a pressure greater than sea level. It may be given in a:

- multi-place chamber (used to treat multiple patients at the same time), compressed to depth by air as the patient breathes 100% oxygen through a face mask or hood
- monoplace chamber (used to treat a single patient), compressed to depth with oxygen. Patients breathe 100% oxygen in the chamber itself. Depending on the treatment depth, patients may wear a mask for medical air breaks for short periods.

Typically, HBOT is given 5 days a week for at least 20 treatments, although the number of treatments varies from 20 to 60. Be aware that HBOT is an adjunctive therapy and must be used in conjunction with normal wound care treatment. It doesn't replace good wound care.

How it works

HBOT improves tissue oxygenation by increasing the amount of oxygen dissolved



in the plasma, thus stimulating healing of chronic diabetic ulcers. Oxygen is essential to wound healing, playing an important role in each wound healing stage. The wound healing rate relates directly to the level of tissue oxygenation; wound ischemia is the most common cause of failure of wounds to heal. Hypoxia in wounds and the wound's responsiveness to oxygen are determined from transcutaneous oximetry monitoring ($TcPO_2$). When measured at the distal lower extremity of a diabetic patient, a normal $TcPO_2$ reading is 30 mm Hg. The decision whether to use HBOT commonly hinges on whether $TcPO_2$ measurements of the periwound area increase significantly with an oxygen challenge.

In this country, HBOT is used with pressures of 2.0 to 3.0 atmospheres absolute, and partial pressures of arterial oxygen (Pa_{O_2}) of 1,200 mm Hg can be attained. At this Pa_{O_2}, hemoglobin is fully saturated (arterial oxygen saturation of 100%), indicating an increased amount of oxygen dissolved in the plasma. Oxygen is perfused into the end-arterioles and tissues, resulting in healing.

Many studies have found beneficial effects of HBOT. Multiple theories address the HBOT mechanism. Known benefits of HBOT in wound healing include enhanced periwound tissue oxygenation, decreased edema, enhanced oxidative killing of bacteria, enhanced cellular energy production, antibiotic potentiation, neoangiogenesis promotion, enhanced epithelial migration, improved collagen production, and enhanced granulation-tissue formation. The effects of cytokines, prostaglandins, and nitric oxide on tissues also may play a major role in how HBOT works. Some literature suggests HBOT mobilizes stem cells derived from bone through a nitric oxide–mediated pathway; these stem cells then migrate to the ulcer and promote healing.

Indications

The Undersea and Hyperbaric Medical Society recommends HBOT for adjunctive treatment of selected problematic wounds, including sufficiently perfused lower-extremity diabetic ulcers. Eligibility guidelines from the Centers for Medicare & Medicaid Services state that patients must have type 1 or 2 diabetes with a lower-extremity ulcer caused by diabetes and classified as a Wagner grade 3 or higher; also, the patient must have failed an adequate course of wound therapy. (See *Wagner ulcer classification system.*)

Contraindications

HBOT has few absolute and several relative contraindications.

- *Absolute* contraindications include untreated pneumothorax and use of

Wagner ulcer classification system

The Wagner system is one of the most commonly used foot ulcer classification systems. This chart describes the five grades in this system.

Grade	Description
0	At-risk foot with pre-ulcer No open lesions; intact skin May show deformities, erythematous areas of pressure, or callus formation
1	Superficial ulcer Skin disruption without extending into subcutaneous layer May have superficial infection
2	Full-thickness ulcer that perforates through fat and subcutaneous tissue to tendon or joint capsule No abscess or osteomyelitis
3	Deep ulcer with abscess, osteomyelitis, tendonitis, or joint sepsis; ulcer extends to these structures
4	Gangrene of geographic portion of foot (such as toes, forefoot, or heel)
5	Gangrene of whole foot beyond salvage, requiring limb- or life-saving amputation

bleomycin, disulfiram, doxorubicin, and mafenide acetate. Contraindicated drugs must be discontinued before HBOT. Also, patients with a pneumothorax must have a chest tube inserted.

- *Relative* contraindications call for caution or consideration, but don't prohibit HBOT. They include seizure disorders, emphysema with carbon dioxide retention, high fever, history of spontaneous pneumothorax, optic neuritis, upper respiratory infection, pregnancy, congenital spherocytosis, and implanted pacemakers or epidural pain pumps. Some types of chemotherapy also are relative contraindications. For example, the cancer chemotherapy agent doxorubicin (Adriamycin) is thought to become cardiotoxic when used concurrently with HBOT. However, the system clears the drug in 24 to 48 hours, so treating patients with HBOT after they've stopped doxorubicin for 2 or 3 days should be safe.

Risks and adverse effects

HBOT is one of the most benign treatments in health care. Nonetheless, it can cause adverse effects. The most common one is ear barotrauma, which occurs when the eustachian tubes close during pressurization, causing increased pressure against the tympanic membrane. Barotrauma effects may vary from tympanic membrane damage to eardrum rupture. Barotrauma damage is classified on the Teed Scale and ranges from grade 0 (no damage) to grade 5 (deep black or blue appearance of the entire ear drum and/or rupture). You can access photos and descriptions for the Teed Scale at **www.docstoc.com/docs/68825188/TEED-SCALE-DESCRIPTIONS**.

Other possible adverse effects include sinus squeeze, tooth squeeze if the patient has an air space under a filling, transient myopia, claustrophobia, oxygen toxicity and, rarely, seizures. In diabetic patients, HBOT has a hypoglycemic effect, reducing blood glucose levels an average of 50 mg/dL during treatment. Caregivers must check the patient's blood glucose level before and after each treatment and postpone treatment if the pretreatment blood glucose level is 100 mg/dL or lower.

Patient considerations related to HBOT center on safety concerns and patient education. (See *Patient considerations for HBOT*.)

Patient considerations for HBOT

Although you may not be directly involved with hyperbaric oxygen therapy (HBOT) treatments, you'll benefit by understanding safety and education considerations.

View: HBOT

Safety

Before patients begin HBOT, they must be checked for potential fire hazards, because oxygen in contact with many items can trigger a fire inside the hyperbaric chamber. Patients should be free from hairspray or gel, makeup, aftershave, metal objects, cell phones, battery-operated devices, and medication patches. They may wear eyeglasses in a multi-place chamber if the glasses don't contain titanium. They shouldn't wear hearing aids because of the risk of fire and because pressurization may change the position of the hearing aid in the ear. Ear plugs are prohibited because they may become lodged in the ear canal.

Education

Explain HBOT to patients, including its risks and benefits, related safety procedures, and what they can expect during therapy based on the type of chamber used. For patients who are overly anxious, consider obtaining an order for a sedative beforehand. Tell patients they will be monitored closely. Instruct diabetic patients to take prescribed medications and eat before HBOT appointments.

Case studies: HBOT in action

The case studies below highlight the value of HBOT in treating diabetic foot ulcers.

Patient #1

This 53-year-old male was referred for treatment of a nonhealing diabetic ulcer of the right foot after fifth ray resection for osteomyelitis and abscess formation in a Wagner grade 4 ulcer. Comorbidities included diabetes mellitus type 2, chronic obstructive pulmonary disease, methicillin-resistant *Staphylococcus aureus* (MRSA), pedal edema, neuropathy, and stroke. Also, the patient was a smoker. The ulcer measured 6.2 cm × 4.6 cm, with a depth of 0.7 cm. $TcPO_2$ measurement showed a baseline of 56 mm Hg, increased to 187 mm Hg during the oxygen challenge, indicating the potential for a response to HBOT. Over 52 days, the patient received 26 HBOT treatments and three debridements, resulting in 100% wound closure.

Right lateral fifth ray resection before HBOT

Right lateral fifth ray resection after 26 HBOT treatments

Patient #2

This 79-year-old male had type 2 diabetes mellitus with a Wagner grade 3 diabetic ulcer of the left dorsal great toe. He'd had ulcers in the same toe 1 year and 2 years before, which had healed both times. Comorbidities included peripheral sensory neuropathy and colon cancer. He was referred by his podiatrist for evaluation and management. On presentation, he had an infection and bone was present at the proximal portion of the ulcer with undermining. The ulcer measured 0.7 × 1.0 cm, with a depth of 0.3 cm. $TcPO_2$ measurement showed a baseline of 48 mm Hg, increased to 198 mm Hg during the oxygen challenge, which indicated potential for a good response to HBOT. Initially, the patient was placed on oral antibiotics. During the course of HBOT sessions, he underwent five debridements; local wound care included Silvasorb gel and pressure offloading.

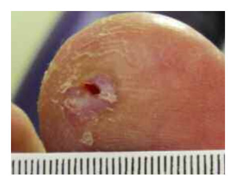
Left dorsal great toe before HBOT

Left dorsal great toe after 40 HBOT treatments

Patient #3

This 70-year-old male with type 2 diabetes mellitus presented with a Wagner grade 3 diabetic ulcer of his right plantar great toe with cellulitis, after toe trauma caused by stepping on a nail that went through the sole of his shoe. He had a history of foot ulcers, necessitating amputation of the left second toe, as well as an ulcer on the right plantar foot. Comorbidities included hypertension, a mild stroke 21 years earlier, and arthritis. The patient exhibited sensory and motor neuropathy. He received both oral and I.V. antibiotics and a tetanus shot. Bone was exposed in the wound bed and X-rays confirmed osteomyelitis. Initially, the wound measured 0.5 cm × 0.4 cm, with a depth of 0.6 cm. During the course of HBOT treatments, he had three debridements and healed completely after 40 treatments.

Right plantar great toe and dorsal view before HBOT



Right plantar great toe after 38 HBOT treatments

Patient #4

This 50-year-old female was admitted with a Wagner grade 3 diabetic foot ulcer with abscess of the left foot, status post-incision and abscess drainage. A bone scan suggested osteomyelitis. Comorbidities includ-

Left plantar foot after 31 HBOT treatments

ed diabetes mellitus type 2, MRSA infection, and sensory and motor peripheral neuropathy. Her history included two episodes of diabetic foot ulcers, which healed. Before HBOT, her ulcer measured 3.4 cm × 1.7 cm, with a depth of 1.3 cm. $TcPO_2$ measurement showed a baseline of 40 mm Hg and a response to the oxygen challenge, demonstrating potential for healing with HBOT. She received I.V. antibiotics and had a total of six debridements during the course of HBOT treatments. After a series of 31 HBOT treatments, she progressed to healing.

An important adjunctive treatment

Systematic HBOT can bring significant reductions in the number of amputations needed, decrease the wound area, and promote healing. It has been effective in healing diabetic foot ulcers by establishing adequate oxygen availability within the vascularized connective tissue compartment around the wound. It also improves local host immune response and helps resolve infection. As the incidence of diabetes increases, HBOT will become an increasingly important adjunctive treatment to provide optimum outcomes and local wound care for patients with diabetic ulcers. ■

Selected references

Daly MC, Faul J, Steinberg JS. Hyperbaric oxygen therapy as an adjunctive treatment for diabetic foot wounds: a comprehensive review with case studies. *Wounds*. 2010; 22(1):1-11.

Driver V, Landowski MA, Madesen JL. Neuropathic wounds: the diabetic wound. In: Bryant R, Nix D, eds. *Acute and Chronic Wounds: Current Management Concepts*. 4th ed. St. Louis, MO: Elsevier Mosby; 2012:237.

Gater L. Hyperbaric oxygen therapy's role in treating chronic foot wounds. *Pod Manag*. 2007;26(9):189-192.

Hinchliffe RJ, Valk GD, Apelqvist J, Armstrong DG, Bakker, et al. A systematic review of the effectiveness of interventions to enhance the healing of chronic ulcers of the foot in diabetes. *Diabetes Metab Res Rev*. 2008;24(1):119-144.

Katarina H, Magnus L, et al. Diabetic persons with foot ulcers and their perceptions of hyperbaric oxygen chamber therapy. *J Clin Nurs*. 2009;18(14):1975-85.

Kindwall E. Contraindications and side effects to hyperbaric oxygen treatment. In: Kindwall E, Whelan H, eds. *Hyperbaric Medicine Practice*. 3rd ed. Flagstaff, AZ: Best Publishing Company; 2008;275-288.

Kranke P, Bennett MH, Martyn-St James M, Schnabel A, Debus SE. Hyperbaric oxygen for chronic wounds. *Cochrane Database Syst Rev*. 2012 Apr 18;4:CD004123. doi:10.1002/14651858.CD004123.pub3.

Londahl M, Katzman P, Nilsson A, Hammarlund C. Hyperbaric oxygen therapy facilitates healing of chronic foot ulcers in patients with diabetes. *Diabetes Care*. 2010;33(5):998-1003.

Lubbers MJ. HBOT in evidence-based wound healing. *EWMA J*. 2010;10(2):10-2.

McHowell W. Care of the patient receiving hyperbaric oxygen therapy. In: Larson-Lohr V, Norvell H, eds. *Hyperbaric Nursing*. Flagstaff, AZ: Best Publishing Co.: 2002;122.

Milovanova TN, Bhopale VM, Sorokina EM, Moore JS, Hunt TK, et al. Hyperbaric oxygen stimulates vasculogenic stem cell growth and differentiation in vivo. *J Appl Physiol*. 2009;106(2):711-28.

Wang CJ, Ko JY, Kuo YR, Yang YJ. Molecular changes in diabetic foot ulcers. *Diabetes Res Clin Pract*. 2011; 94(1):105-10.

Wang CJ, Wu RW, Yang YJ. Treatment of diabetic foot ulcers: a comparative study of extracorporeal shockwave therapy and hyperbaric oxygen therapy. *Diabetes Res Clin Pract*. 2011;92(2):187-93.

Warriner R, Hopf H. Enhancement of healing in select problem wounds. In: Gesell L. Hyperbaric Oxygen Therapy Indications. 12th ed. Durham, NC: Undersea and Hyperbaric Medical Society; 2008; 71-72.

Wilcox J, Paez N. Managing chronic wounds at the cellular level: the diabetic foot ulcer. *Wound Care Hyperbar Med*. 2011;2(1):12-21.

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