The Effect of Hyperbaric Oxygen on Lower Extremity Ulcerations

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The authors discuss the use of hyperbaric oxygen in the treatment of lower extremity skin ulcers. In this study, ulcers were of various etiology and were refractory to outpatient management. This modality was employed with both medical and surgical management. We report total healing in all patients.

The treatment of lower extremity ulcerations is most challenging. There are numerous treatment regimens for the various types of ulcers and underlying medical pathologies. Therapy must be tailored to the particular needs of the patient, as well as to the etiology of the ulcer. This paper discusses the use of hyperbaric oxygen, a modality which can be combined with most treatment plans and can be used to treat virtually any ulcer, regardless of cause.

The goal of ulcer treatment is the promotion of healthy granulation tissue and subsequent epithelization. The elimination or control of the underlying etiology, the promotion of circulation, and the removal of necrotic debris at the ulceration site, requires various modes of therapy, usually in conjunction with each other.

Enzymatic debridement is preferred when vascular insufficiency exists. Ischemic ulcerations require great care to prevent infection and trauma to the already fragile tissue.

Numerous authors review the use of enzymatic debridement of ulcers. They have shown to be effective in removing purulent exudate and necrotic tissue. Enzymes have been successfully utilized with decubitus ulcers secondary to peripheral vascular disease or neurological illness.[1-3]

Porcine skin grafts are also used on decubitus, neuropathic, stasis, and ischemic ulcers. Decubitus and neuropathic ulcers were the most responsive to porcine grafts. Stasis ulcers showed comparatively less granulation while ischemic ulcerations were the most difficult to treat. The grafts apparently decreased the pain but did little toward achieving a cure. The porcine is thought to work by lessening or eliminating sepsis and serving as a foundation for granulation.[4, 5]

Debrisan®[1] hydrophilic beads appear to aid ulcer healing by absorbing the exudate. Debrisan is a viable alternative to an enzyme and appears to act more rapidly.[6]

Twenty percent benzoyl peroxide solution, applied topically to ulcers, was first used as a protective barrier. Benzoyl peroxide-soaked sterile gauze is applied to the ulcer and covered with plastic wrap. This dressing is then changed every 8 hr and may be used on an outpatient basis. The benzoyl peroxide is believed to release oxygen into the superficial tissue. Molecular oxygen is necessary for aerobic cellular respiration of the fibroblast and is an essential element in wound healing. Benzoyl peroxide slowly liberates molecular oxygen and constantly increases the oxygen tension in the tissue. Bacteriocidal effects are also noted.[7] An increase in tissue oxygen levels is also achieved by the use of hyperbaric oxygen.

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[1] Pharmacia Inc, Piscataway, NJ.

Olejniczak," in 1966, reported on 35 patients with skin ulcers treated with hyperbaric oxygen delivered through a nylon bag. The bag was held in place over the ulcer with a tourniquet. Other methods of oxygen delivery include leg sleeves, individual tanks, and walk-in chambers.[9-11]

Hyperbaric oxygen has been used to treat almost every type of ulcer. Bass[12] reports treating select patients with varicose ulcers. Torelli[13] employed this method for decubitus ulcers of nursing home patients. There are additional reports of this therapy for ulcers caused by burns, postoperative infections, rheumatoid arthritis, hypergammaglobulinemia,[14] sickle cell anemia, arteriosclerosis, lupus erythematosus, and diabetes mellitus.[15, 16]

Specific treatment regimens also vary. Pressures as low as 22 mm of Hg above atmospheric pressure (1.03 atmospheres)[14] to as high as 3 atmospheres are used.[17] Treatment periods range from 20 min/day[18] to several h/day.[17] Hyperbaric treatment may be employed as a solitary treatment modality, in combination with saline dressings, or with various topical agents and/or antibiotics. Hyperbaric oxygen may also be used in conjunction with porcine skin xenografts.[19]

Hyperbaric oxygen has been most successful in healing venous ulcers. Fischer[20] discusses the treatment of 16 people with venous stasis ulcers. The average healing time was 15 days. In another study, 87 of 91 postphlebitic ulcers were healed completely. The latter study also reported the healing of 11 ulcers caused by varicose veins.[15]

Rosenthal and Schurman[17] report 58% of decubitus ulcers treated with hyperbaric oxygen completely healed, while an additional 13% of the ulcers were reduced by at least half their original size. In 1975, Fischer[14] reported healing 16 cases of pressure ulcers within 2 months of treatment. Hyperbaric oxygen also proved beneficial to ulcers secondary to trauma.[15]

Hyperbaric oxygen treatment is most effective on ulcers with an adequate vascular supply. A high failure rate is found in ulcers with a poor blood supply. Olejniczak and Zielinski[15] report only a 33% healing rate of arteriosclerotic ulcers. Others report similarly poor results with ischemic ulcers.[14, 17]

Hyperbaric oxygen forces an increased amount of oxygen to dissolve in the superficial plasma of the ulcer.[18] The high oxygen content in the superficial aspects of the treated ulcer enhances healing. The deeper aspect of the wound is healed by the body's own blood supply, if present. This vascular source is usually adequate when ulcers are of venous origin. However, when ulcers are caused by ischemia, there is little or no deep blood supply. The hyperbaric oxygen cannot readily aid the deep parts of the wound.

Material and Methods

This paper evaluates the efficacy of the hyperbaric oxygen in the treatment of skin ulcers. The results are reported as both retrospective and prospective studies.

A review of recent hospital records revealed four ulcer patients treated with hyperbaric oxygen. These cases were reviewed and are presented as an overview. Seven new patients were monitored as a prospective study. Weekly subjective and objective measurements were made.

The hyperbaric oxygen therapy was used together with standard ulcer care. A Topical Hyperbaric Oxygen Chamber[*2] was utilized. A pressure of 22 mm of Hg was employed with a flow rate of 4 liters/min. All treatments were 90 min, twice a day.

All cases were evaluated on the basis of the following parameters: history, bandage condition, condition of the lower extremities, ulcer measurements, subjective and objective observations, x-ray evaluation, and culture results (Fig. 1).

Results

Eleven patients, refractory to outpatient management, are described. Etiologies and healing times are summarized in Table 1.

The following four patients are presented from a review of hospital records.

Patient #1. J. S., an 85-year-old black male, was admitted with an ulcer of the right leg. The ulcer was severely infected and necrotic, measuring 8 × 5 cm. The past medical history included diabetes mellitus and ischemic heart disease.

The lower extremity was edematous with generalized erythema. Pulses in the left foot were very weak and were totally absent in the involved foot.

A culture revealed Proteus and Pseudomonas species. The patient was treated with numerous topical medications and systemic antibiotics. The ulcer was surgically debrided numerous times. After the last debridement, postage stamp skin grafts were applied.

The patient received hyperbaric oxygen treatment throughout his hospital stay. He was discharged after 2 months, completely healed.

Patient #2. E. B., a 59-year-old black male, was admitted with a venous stasis ulcer on the lower lateral aspect of the right leg. He was admitted after

[*2] Topox Corporation, Jersey City, NJ.

mitted with chronic venous insufficiency and a varicose ulcer of the left medial malleolar area. The ulcer had been present for 4 months with treatment consisting of Betadine[83] soaks and "electrical stimulation."

He was then hospitalized for treatment of venous insufficiency and a painful leg ulceration. The lesion was a well circumscribed, smooth ulcer measuring 2 × 2 cm, proximal to the left medial malleolus. The ulcer was moderately dry but contained α Streptococcus. The surrounding area was hyperpigmented with patches of stasis dermatitis. All pedal pulses were palpable.

Hyperbaric oxygen therapy was used in conjunction with saline soaks and Elase[84] ointment. By the seventh day of treatment, the ulcer was slightly improved, with a marked reduction of pain. Six days later, hyperbaric oxygen was stopped, and a left saphenous vein ligation and stripping were performed. Two days later, the ulcer edges were surgically approximated. A total of 17 days was required for wound healing.

Patient #6. A 25-year-old Caucasian male was admitted with arterial insufficiency, cellulitis, and ulceration of the right lower extremity. Approximately 6 months prior to admission, the patient noticed an ulcer on the anterior aspect of the lower third of the right leg. He could not remember any trauma to the area. He was unsuccessfully treated on an outpatient basis for 2 months.

Upon admission, there was a well circumscribed, raised, dry ulceration measuring 1 cm^2, 1–2 mm deep, with granulation tissue present. The ulcer was surrounded by an erythematous area measuring 8.5 × 14 cm. A venogram demonstrated varicosities of the right lower leg with no blockage. All pulses were good.

The treatment regimen consisted of portable hyperbaric oxygen therapy, enzymatic debridement, and parenteral cephalosporins for treatment of a *Staphylococcus aureus* infection. By the third day of treatment, the ulcer had considerably reduced in size.

After 8 days of treatment, granulation of the lesion was almost complete, with the erythematous area almost completely resolved. On day 19, the patient was discharged from the hospital with the leg ulceration completely healed.

Patient #7. A 77-year-old black male diabetic and hypertensive patient was admitted with a severely ulcerated left fifth toe and cellulitis. The ulcer developed 3 months prior to admission as a result of self-debridement. Past treatment consisted of saline soaks and topical antibiotics, all without success.

The ulcer was bloody and necrotic, measuring 0.7 × 1.5 cm with a depth of 2 mm. The periphery was raised and irregular. All pedal pulses were palpable. Therapy consisted of hyperbaric oxygen, Mefoxin[85], and Diabenase[86]. The ulcer was kept moist with saline soaks.

After 2 days of therapy, there was new granulation of the ulcer. The healing process was progressive with almost total healing by day 10. On the thirteenth day, the patient was discharged with the foot ulcer completely healed.

Patient #8. A 72-year-old black female was admitted with an ulcer proximal to the left medial malleolus which had been present for 15 years. Past treatment improved her condition, but the ulcer never completely healed. Treatments included rest, antibiotics, saline soaks, topical enzymes, and venous ligations. Her medical history included diabetes mellitus, hypertension, and varicose veins.

The ulcer was well circumscribed, moist, and bloody, measuring 1.5 cm^2. The ulcer base contained granulation tissue with a small central black eschar. The periphery of the ulcer was depigmented closest to the center with a hyperpigmented area most eccentrically. Pseudomonas was cultured from the ulcer site. Pedal pulses were palpable.

Hyperbaric oxygen therapy was employed along with antibiotics. By the end of the first week of therapy, the ulcer had healed with an eschar formation measuring 1 cm^2. The hypopigmented periphery had disappeared and the hyperpigmented area had diminished in size. The ulcer continued to heal, and by 3 weeks, the eschar was less than 1 cm, with a very small hyperpigmented periphery. At the time of discharge 21 days later, the eschar measured 0.5 cm, with only minimal hyperpigmentation and edema.

Patient #9. A 61-year-old black male was admitted with an ulcer proximal to the right medial malleolus. The ulcer started 1 month prior as a soft tissue mass which abcessed and was then incised and drained.

He was admitted to the hospital with the ulcer, cellulitis, and lymphangitis. His medical history included arterial disease.

The ulcer was moist with a red granulating base measuring 3.5 × 2.5 cm. The ulcer was 1-cm deep with exposed tendon. The culture was negative. Pedal pulses were barely palpable.

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[83] Purdue Frederick, Norwalk, CT.
[84] Parke-Davis, Morris Plains, NJ.
[85] Merck, Sharp and Dohme, West Point, PA.
[86] Pfizer Laboratories, New York, NY.

Following 2 weeks of hyperbaric treatment, a skin graft was performed. After 2 additional weeks of hyperbaric oxygen, the ulcer was totally healed.

Patient #10. A 66-year-old black male was admitted with cellulitis of the right second toe, extending to mid-calf. The toe had been infected for 7 months. Two weeks before admission, the patient stubbed his toe and developed a marked cellulitis. His medical history included alcoholism and hypertension.

The second toe was ulcerated on the dorsal surface over the proximal interphalangeal joint. The toe was markedly edematous. Drainage was present and was cultured as β Streptococcus. Radiographic analysis indicated partial dislocation of the second proximal interphalangeal joint with erosion of the head of the proximal phalanx, suggesting osteomyelitis. All pedal pulses were adequate.

Hyperbaric oxygen therapy for the right leg was combined with antibiotic therapy. The ulcer was kept moist between treatments with saline dressings.

By the third day of treatment, there was a reduction of the edema and of the amount of discharge. Pain was also decreased. Two days later, the ulcer superficially closed, and the culture was negative. The patient was discharged after 17 days, with the ulcer completely healed.

Patient #11. A 65-year-old black male was admitted with a severely ulcerated right heel and cellulitis. The ulcer developed 15 years prior to admission, secondary to trauma. During these 15 years, he has had continual exacerbations and remissions with severe pain and significant drainage. His past treatments have included antibiotics, enzymes, debridement, and rest.

At the time of hospitalization, the ulcer measured 5 × 3 cm, with the calcaneus partially exposed. Proteus was cultured from the ulcer site. A bone scan was performed and revealed "possible osteomyelitis." No pedal pulses were palpable.

Treatment consisted of hyperbaric oxygen, Mefoxin, and surgical debridement of the calcaneus and overlying tissue. The ulcer site showed constant improvement and his pain reduced within 2 weeks. A second culture was negative. One week later, the ulcer was superficially healed, and the patient was discharged.

Discussion

There are numerous theories postulating the mechanism of action of hyperbaric oxygen treatments. Previous studies[18, 21] demonstrate that during hyperbaric oxygen treatment there is an increased oxygen saturation in the plasma covering of the ulcer and in the superficial layers of the granulation tissue. Olejniczak[18] found that when oxygen was employed under a pressure of 22–25 mm of Hg (1.03 atmospheres), the pO_2 values gradually increased from the initial value of 50 mm of Hg to an average of 450 mm of Hg. Two min after termination of the treatment, the pO_2 returned to its original value. Oxygen applied under ambient pressure has little penetrance of the epidermis.[21] However, a pressure exceeding 22 mm of Hg will cause obstruction of capillary blood flow and should be avoided.[18]

Uptake of oxygen at the ulcer site is also dependent on the skin thickness and viability. The hyperbaric oxygen supplements oxygen to the superficial tissue of the ulcer which is not sufficiently supplied from the blood stream. This effect was observed in the venous ulcers of Patients 2, 3, 5, and 8. Oxygen under a pressure of up to 3 atmospheres will not significantly elevate pO_2 of the deeper layers, which is dependent upon the oxygen supply from the vascular bed. This superficial effect helps explain the usual lack of success in the healing of leg ulcers associated with advanced arteriosclerosis.[15, 18, 21] However, all arterial insufficiency ulcers (Patients 4, 6, 9, and 11) were helped by hyperbaric oxygen.

Many authors speculate on the role of hyperbaric oxygen in wound healing. Olejniczak[18] described a two phase healing process. The first phase is a cleansing, self-debriding period, extending from 1 to 10 days. During this time, the exudate disappears and necrotic tissue sloughs off. There is the appearance of fresh red granulation tissue on the surface with new, well outlined edges. The second stage is characterized by rapid growth of granulation tissue filling the ulcer at the same pace with epithelium. The cleansing and debriding effects are important when preparing the ulcer site for a skin graft. Following hyperbaric therapy, successful grafting was performed on Patients 1 and 9.

It has been proposed that oxygen plays an important role in wound healing by increasing the rate of epithelization, the synthesis of collagen by fibroblasts, and the degree of cellular differentiation.[22, 23] Rosenthal supports these findings and states that the metabolic processes of the tissues proceed more quickly with hyperbaric oxygen, thus hastening the healing process.[17] One should note that only viable tissue allows penetration of the incoming oxygen, whereas necrotic skin is somewhat resistant to the diffusion of oxygen. Therefore, adequate surgical or enzymatic debridement is essential for optimal results.

The ulcers in this study displayed a variety of