Hyperbaric oxygen therapy for the management of chronic wounds: patient selection and perspectives

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Abstract: The Undersea and Hyperbaric Medical Society includes “select problem wounds” as an accepted indication for the use of hyperbaric oxygen (HBO₂), however, the treatment of diabetic foot ulcers (DFUs) has dominated any discussions of problem wounds because of the prevalence of DFUs in today’s patient population and the reimbursement available for their treatment. Other wound types (eg, calciphylaxis ulcers, sickle cell ulcers, and pyoderma gangrenosum) that have well-deserved reputations as problem wounds have been infrequently treated with HBO₂. While there are sound fundamental reasons why additional oxygen may have benefits in the treatment of these wounds, the challenge is finding enough high quality evidence to support routine use of HBO₂.

Keywords: hyperbaric oxygen therapy, HBO₂, oxygen, problem wounds, chronic wounds, wound healing, diabetic foot ulcers, arterial insufficiency ulcers, sickle cell disease, scleroderma, calciphylaxis, graft versus host disease, pyoderma gangrenosum, venous stasis ulcers

The role of oxygen in wound healing

Oxygen is involved in nearly every phase of wound healing, acting as a critical co-factor for fibroblast replication, collagen deposition,¹ angiogenesis,²⁻⁵ resistance to infection,⁶⁻⁸ and intracellular leukocyte bacterial killing.⁶ Tissue hypoxia, on the other hand, is the initiator of wound healing and leads to upregulation of hypoxia-inducible factors (HIFs) that play a central role in adapting the body to a hypoxic environment. These adaptations include angiogenesis, anaerobic glycolysis, cellular mobility, growth factor signaling, and erythropoiesis.⁹ Wounds become hypoxic as a result of acute or chronic injury.

Hemostasis is the first phase of wound healing. Vasoconstriction, platelet aggregation, and formation of a fibrin clot stop bleeding but also cause local ischemia and hypoxia as vessels thrombose.¹⁰ Wound hypoxia is exacerbated by underlying conditions that result in decreased perfusion to the wound (eg, decreased cardiac output, increased peripheral vascular resistance, and presence of peripheral arterial disease [PAD] or pulmonary dysfunction). Oxygen carrying capacity is determined by the hemoglobin dissociation curve. Although anemia results in decreased overall O₂ carrying capacity, it does not inherently inhibit wound healing.¹¹ Arterial pO₂ is the key factor in wound healing potential and can be modulated through vasodilation, improved cardiac output, capillary permeability, and increased alveolar pO₂ achieved under hyperbaric conditions.¹⁰

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The inflammatory phase begins a few days after injury as neutrophils and monocytes begin the process of breaking down and clearing cellular debris.¹⁰ Macrophages take the lead in breaking down devitalized tissue and killing bacteria,^{10,12} however, oxidative killing is depressed in patients with local wound hypoxia. A minimum tissue pO_2 of 30 mmHg is required for effective bacterial killing.⁷ Neutrophils killed 37% of organisms in 1 hour under anoxic conditions, 58% when pO_2 was raised to 5 mmHg, and 70% at 30 mmHg. There was a minimal increase in killing efficiency when tissue pO_2 was further increased to 150 mmHg.¹³ Neutrophil bacterial killing activity depends on an oxygen-dependent respiratory burst where neutrophils convert oxygen to superoxide.¹⁴ This process can result in a 20–100 fold increase in oxygen consumption^{15,16} and a decrease in tissue pO_2 from 60 mmHg down to 0–10 mmHg.¹⁷ Superoxide production is at its maximal rate at a tissue pO_2 of 300 mmHg but is cut in half with tissue pO_2 between 80–150 mmHg.¹⁸ There is synergy between antibiotic administration and hyperoxia, as early antibiotic administration combined with hyperoxia resulted in more efficient bacterial clearance than delayed administration of either antibiotics or oxygen.⁸ Higher inspired oxygen has also been shown to decrease the spread of infectious necrosis.⁶

The proliferative phase of wound healing sees an increase in collagen deposition, angiogenesis, granulation tissue formation, and epithelialization,¹⁰ but all of these are directly related to wound pO_2 .^{1,19–21} Fibroblast activity, especially collagen synthesis, is a key component in wound healing. Collagen cannot be synthesized without oxygen.²² The minimum tissue pO_2 for collagen synthesis is 25 mmHg, so tissue pO_2 below that results in decreased collagen deposition²³ and lower quality collagen as tensile strength increases with high pO_2 and decreases with high pCO_2 .¹ Angiogenesis and vasculogenesis are both increased through hyperoxia.^{24,25} Stem progenitor cells (SPCs) have been identified as playing a role in vasculogenesis, and studies suggest that HIF-1 plays an important role in directing circulating SPCs to ischemic tissue.⁹ The mitosis rate of squamous cells is oxygen dependent,²⁶ and epithelialization increases with hyperoxia and decreases with hypoxia.^{20,27,28}

Remodeling is the final phase of wound healing and occurs weeks to months after a wound is epithelialized. Immature collagen, which is thinner than mature collagen and deposited parallel to the skin,²⁹ is reorganized into a more structurally sound lattice. Cross-linking of collagen fibers increases wound strength over the next 4–5 weeks.¹⁰

Tensile strength of a newly epithelialized wound is only 3% at 1 week, 20% after 3 weeks, and 80% after 3 months. The ultimate strength of the wound depends on both the quality and quantity of the collagen,¹⁰ which is dependent on wound oxygenation.

In summary, acute injury causes wound hypoxia that is magnified if there is pre-existing ischemia and hypoxia in the wound. Wound pO_2 further decreases as vessels thrombose in the hemostasis phase, leukocytes consume oxygen in the inflammatory phase, and fibroblasts consume oxygen in the proliferative phase.³⁰ Importantly, a healing wound has a higher metabolic demand than when it is in a steady state. This is evidenced by depression of wound-tissue pO_2 in the first few days after a major surgery.³⁰ Wound pO_2 is the rate limiting step in healing, especially in the acute post-operative phase, as the amount of O_2 extracted rises with increased oxygen breathing.²³

Defining the chronic, problem wound

A chronic wound can be defined as a wound that does not heal after an expected period of time. Chronic wounds are often trapped in the inflammatory phase of wound healing, unable to transition into the proliferative phase. Common causes for inflammation include infection, devitalized tissue that has been incompletely debrided, mechanical insults from retained foreign body or external pressure, and hypoxia as a result of wound ischemia. Initial efforts should focus on correcting or ruling out these causes of wound chronicity.

We have enumerated many examples where tissue hypoxia can hinder wound healing.

Local tissue hypoxia may be caused by macrovascular disease with or without concomitant microvascular disease. Macrovascular status can be evaluated using ankle-brachial index, pulse volume recordings, arterial Doppler, computed tomography/magnetic resonance angiogram, and angiography. Presence of macrovascular disease should result in a vascular consultation to determine whether revascularization is possible. Microvascular disease may be evaluated using skin perfusion pressure, transcutaneous oxygen measurement (TCOM), and indocyanine green fluorescence angiography (ICGA).

TCOM is a non-invasive study that measures the pO_2 of tissue ($TcPO_2$) through intact skin.³¹ This provides an objective means of assessing local tissue hypoxia and identifying wounds with a high risk of non-healing or amputation. Electrodes are usually placed adjacent to the

ulcer on the peri-wound skin while others may be placed on the contralateral limb for comparison or on the chest wall to measure normal values. TcPO₂ values have been shown to be useful predictors of wound healing and response to hyperbaric oxygen (HBO₂).^{31–34} TcPO₂ measurements while breathing normobaric room air <40 mmHg are considered hypoxic and associated with a reduced likelihood of healing. TcPO₂ values <35 mmHg while breathing 100% normobaric oxygen are associated with a 41% failure rate with HBO₂.³³ A sea-level oxygen challenge can help predict whether a wound will respond to HBO₂. A wound that is hypoxic on room air (TcPO₂<40 mmHg) but has a rise in TcPO₂>35 mmHg and more than double the room air TcPO₂ while breathing 100% normobaric oxygen, is likely to benefit from HBO₂.³³ The most valuable predictor of response to HBO₂ is the TcPO₂ while breathing 100% O₂ under hyperbaric conditions.³² An in-chamber TcPO₂>200–299 mmHg had significantly reduced wound failure rates.³² In-chamber TcPO₂>200 mmHg had an 84% likelihood of benefit from HBO₂³³ while in-chamber TcPO₂<100 mmHg had only a 14% likelihood of benefit from HBO₂.³¹

In-chamber TcPO₂ was used to determine the appropriate treatment pressure for patients undergoing HBO₂ to treat lower extremity wounds.³⁵ The study used an in-chamber TcPO₂ target of 250 mmHg for decision-making and demonstrated that nearly 80% of patients reached a TcPO₂>250 mmHg at 2 ATA. For patients with a TcPO₂<250 mmHg at 2 ATA, nearly half (41%) reached a TcPO₂>250 mmHg when chamber pressure was increased to 2.4 ATA. This monoplace-based HBO₂ protocol allowed objective choice of treatment pressure that maximized benefit while minimizing risk.³⁵

ICGA is a newer technology that assesses microvascular skin perfusion using an intravenous injection of ICG followed by imaging with a near-infrared laser camera. It has been used extensively by surgeons in the operating room.^{36–40} Recent publications have reported its use for HBO₂ patients with soft tissue radionecrosis,^{41,42} and for assessing perfusion in chronic wounds being treated with HBO₂.⁴³ While this is a very promising tool, there is more work that needs to be done to determine clinical decision-making parameters surrounding ICGA.⁴⁴

While clinical evidence supports the use of HBO₂ in the treatment of non-healing diabetic foot ulcers (DFUs),^{45,46} the variable results seen in actual clinical use suggest that we need to do a better job with patient selection.⁴⁷ Patient selection becomes even more critical

when considering HBO₂ for less established problem wound types. Concern for tissue hypoxia or hypoperfusion should be considered before deciding to use adjunctive HBO₂,⁴⁸ but it should not be the sole determinant in deciding to use HBO₂ as some of its systemic effects (eg, endothelial progenitor stem cell mobilization) are not measured by tissue oxygenation.^{49,50}

Physiological effects of HBO₂

HBO₂ addresses the fundamental issue of wound hypoxia by providing oxygen to ischemic tissue. The amount of O₂ dissolved in plasma is inconsequential at sea-level atmospheric pressure; however, there is enough oxygen dissolved in plasma when breathing 100% O₂ at 3 ATA to meet the body's metabolic demands without dissociation of any O₂ bound to hemoglobin.⁵¹ Oxygen diffusion from capillary beds increases ten-fold and PaO₂ exceeds 1,500 mmHg with corresponding elevation of soft tissue and muscle PO₂. Tissue PO₂ increases in a direct linear relationship to the increased PaO₂ present in the circulating plasma,⁵² allowing healing to proceed.

As opposed to breathing oxygen at sea-level atmospheric pressure, HBO₂ reduces ischemia-reperfusion (IR) injury, mobilizes circulating SPCs, enhances neutrophil bacterial killing activity, produces both reactive oxygen species (ROS) and reactive nitrogen species (RNS), and stimulates multiple growth factors that promote wound healing.⁵³ HBO₂ reduces the perivascular edema and inflammation seen with IR injury by inhibiting the adherence of neutrophils to previously ischemic vascular endothelium, but it does not inhibit the normal antimicrobial functions of degranulation, phagocytosis, or the oxidative burst.^{54–56} HBO₂ is involved in the recruitment and differentiation of circulating SPCs to form vessels de novo.^{24,49,53} The knowledge that HIF-1 helps direct circulating SPCs to ischemic tissue⁹ suggests that the combination of HIF-1 activity and HBO₂ may be the basis for improved healing seen with HBO₂ therapy.⁵⁷ Conversely, HIF-1 has been shown to break down rapidly in non-hypoxic environments⁵⁸ and others have shown that HBO₂ improves wound healing by down-regulating HIF-1 α ,⁵⁹ highlighting that we have an incomplete understanding of the complex interactions between HIF and HBO₂.

ROS and RNS are important signaling molecules that are involved in the regulation of various hormones, growth factors, and cytokines involved in wound healing. ROS such as superoxide (O₂^{•-}), hydrogen peroxide (H₂O₂), hypochlorous acid (HClO), and hydroxyl (HO[•]) are the

natural by-products of normal metabolism, and RNS include nitric oxide (NO) and peroxynitrite (ONOO⁻) – the product of NO and O₂⁻. NO is synthesized by three NO synthase enzymes: NOS-1 (nNOS), NOS-2 (iNOS), and NOS-3 (eNOS). Bone marrow eNOS activity is required for SPC mobilization – a function that is depressed in diabetic patients – and HBO₂ is able to stimulate eNOS activity, resulting in up-regulation of SPC production.^{25,49,53,57} Reactive species may have either positive or negative effects, depending on their concentration and intracellular localization.⁶⁰ A complete discussion of the role of ROS and RNS in wound healing is beyond the scope of this review, and readers are directed to Thom's manuscript for more details.⁶⁰ The body needs to balance the ROS that are generated as a part of normal metabolism with its natural anti-oxidant defenses. An inability to maintain balance results in oxidative stress, which can be seen where an overproduction of ROS in chronic wounds leads to a prolonged inflammatory state.⁶¹ When speaking about HBO₂, it is important to realize that oxidative stress and oxygen toxicity are not synonymous,⁵³ and the body's inherent anti-oxidant defenses are able to manage the oxidative stress seen in the intermittent use of HBO₂.^{62–68} NO, a potent vasodilator, is reduced in non-healing diabetic wounds; however, increased NO levels after a course of HBO₂ treatments correlated with successful healing.⁶⁹

HBO₂ increases synthesis of a laundry list of growth factors: VEGF,⁷⁰ TGF-β₁,⁷¹ bFGF,⁷¹ angiopoietin-2,⁷² MMP-2 and MMP-9, TIMP-1,⁷³ and PDGF receptors.⁷⁴ Collagen synthesis, which is very sensitive to PO₂, is augmented by HBO₂.² Epithelialization is increased by approximately 30%,²⁷ but wound contraction is unaffected by ambient pO₂.²⁰ HBO₂ has been shown in cell cultures to up- or down-regulate over 8,000 different genes at the molecular and cellular level with large responses only when exposed to HBO₂ and not sea-level 100% oxygen.⁷⁵

If oxygen availability is the rate limiting step in wound healing and O₂ consumption increases as O₂ availability increases,²³ it stands to reason that further increases in available pO₂ during HBO₂ would enhance wound healing. In addition to the effects of hyperoxia, alternating periods of hypoxia or relative hypoxia (compared to HBO₂) may stabilize HIF, which primes the wound for a more robust response during the next period of.⁷⁶ This push-pull relationship may explain how HBO₂ plays a role in enhanced healing of chronic, problem wounds.

Patient selection for HBO₂

Although there are sound fundamental principles supporting the use of HBO₂ for chronic wounds,⁷⁷ the evidence for some of these conditions is limited to case reports and case series. There are very few randomized controlled trials, and the variability in scientific rigor has led many to question their conclusions.⁷⁸

DFUs

The largest body of evidence in support of HBO₂ is found in the treatment of DFUs. Patients with diabetes mellitus commonly have sensory, motor, and autonomic neuropathy as well as macrovascular and microvascular angiopathy, leading to ischemic and hypoxic wounds that are prone to ulceration and infection.⁷⁹ There is decreased mobilization of circulating SPCs⁸⁰ and suppression of NO, reducing healing potential. As detailed previously, HBO₂ reverses local tissue hypoxia, stimulates vasculogenesis, directs SPCs to ischemic tissue, and stimulates multiple growth factors that enhance wound healing and vasculogenesis.^{49,53,69–71,74,81–83}

A thorough summary and analysis of the hyperbaric literature regarding DFUs was published in 2017⁸⁴ and updated in 2019.⁸⁵ Readers are referred to these publications for a more in-depth discussion. Early studies showed that the use of HBO₂ was able to reduce the incidence of lower extremity amputation. Amputation rates decreased from 30%–40% without HBO₂ to only 5% with adjunctive HBO₂.^{86–89} Randomized controlled trials demonstrated that HBO₂ reduced the number of positive wound cultures,⁹⁰ reduced major amputation rates,^{88,90} and increased the rate of wound healing.^{91–94} Transcutaneous oximetry was shown to be a predictor of wound healing potential, but only when looking at TCOM values while breathing HBO₂.^{31–33,48,95} A fundamental tenet for the consideration of adjunctive HBO₂ is whether or not basic wound care principles have been followed prior to instituting HBO₂.^{96,97} Criteria for the use of HBO₂ were established in the United States by the Centers for Medicare and Medicaid Services (CMS) based on the result of a pivotal trial that utilized the Wagner Grading system⁸⁸ even though there are other grading systems that are more sophisticated and arguably more clinically relevant.⁹⁸

A large longitudinal cohort study of 6,259 patients with a plantar DFU questioned the effectiveness of HBO₂, showing that patients receiving HBO₂ had a lower healing rate (42.3% vs 49.6%), higher overall amputation rate (6.7% vs 2.1%), and higher major amputation rate (3.3% vs 1.3%) than patients who did not receive HBO₂.⁴⁷ This study

highlighted the difference between the efficacy of HBO₂ as shown in tightly controlled clinical trials vs how patients were treated in a real-world scenario, but it was criticized for its reliance on propensity scoring to account for the lack of randomization between treatment groups.^{91,99} Two recent randomized controlled trials also failed to show a benefit for HBO₂ in healing DFUs or reducing amputations,^{100,101} but one was hampered by the use of photographs to adjudicate whether a wound met pre-determined criteria for amputation rather than amputation itself,^{102–104} and the other showed that a high percentage of patients did not start or could not complete the prescribed treatment protocol.^{105,106} When considering patients who did complete the protocol, however, HBO₂ was able to show significantly fewer amputations than standard care alone.¹⁰¹ This is consistent with several other studies that showed that patients who underwent a longer course of therapy had successful wound healing, while those with shorter courses did not.^{31,107,108}

The UHMS developed a set of clinical practice guidelines to help the hyperbaric provider judiciously use HBO₂ as part of the treatment plan. Even though CMS guidelines restrict HBO₂ for Wagner Grade 3 DFUs or higher, over 45% of patients in multiple studies had only Wagner Grade 2 DFUs.^{47,100,101} The UHMS found insufficient high-quality evidence to suggest using HBO₂ in the treatment of Wagner Grade 2 DFUs. It did find enough evidence to suggest treating Wagner Grade 3 or higher DFUs that were either refractory to wound healing and had been present for 30 days, or for acutely infected Wagner Grade 3 or higher DFUs that required urgent surgical intervention.⁴⁶ HBO₂ was shown to be more effective than standard therapy when restricted to only Wagner Grade 3 and 4 DFUs.¹⁰⁸ Cost effectiveness studies comparing HBO₂ with the cost of an amputation with subsequent rehabilitation and physical therapy have been uniformly favorable toward HBO₂,^{109–113} and the integration of HBO₂ into a comprehensive limb salvage protocol has been advocated.^{87,113}

DFUs remain the most common chronic wound type being treated with HBO₂, but tightening requirements for reimbursement are constraining the frequency of its use. This may be wholly appropriate, given the rapid rise in outpatient wound and hyperbaric centers,¹¹⁴ but there is a risk of denying limb-saving therapy to a patient who truly requires it.

Arterial insufficiency ulcers (AIUs)

Between 8–12 million people in the United States over 40 years of age are affected by PAD¹¹⁵ and suffer tissue ischemia due to atherosclerosis.¹¹⁶ AIUs are closely

related to DFUs as the majority of patients with DFU also have PAD. These patients are often unable to be revascularized, leaving an above-ankle amputation as their only alternative. Healing rates with revascularization are reported between 50%–90% with amputation rates of <20%.^{117,118} Outcomes change dramatically without revascularization, however, with healing rates of 40%–50% and amputation rates between 25%–40%.^{117,118}

HBO₂ reverses local tissue hypoxia and stimulates vasculogenesis, however it is less effective in the face of severe macrovascular disease. Inability to revascularize the lower extremity is not a reason to exclude HBO₂ from the treatment plan. A commonly overlooked aspect of the DFU studies previously mentioned is whether or not they include patients with underlying, uncorrectable vascular disease. While many wound healing studies excluded patients with significant PAD, the Faglia study included patients who had persistent tissue hypoxia and still showed increased healing and decreased amputation rates.⁸⁸

There are very few studies to guide patient selection for HBO₂, but a case series of 82 patients with AIUs in the absence of diabetes mellitus showed a significant clinical response to HBO₂.¹¹⁹ The Wound Healing Society recommends consideration of HBO₂ if patients have an AIU refractory to revascularization or if they are not a candidate for revascularization.¹²⁰ Any decision to use HBO₂ for an AIU should be done after a thorough arterial insufficiency workup, although it may be considered as a bridging therapy to preserve ischemic tissue until definitive revascularization can occur. Objective measurements of tissue ischemia and hypoxia should be used to guide patient selection and monitor response to therapy, although there are no clear-cut criteria in the literature.

Calciphylaxis

Calciphylaxis is a rare condition that causes small vessel calcification of unknown etiology. This can present as painful skin lesions and chronic, non-healing ulcers with gangrene. Calciphylaxis is reported to have a prevalence of 1%–4% in end-stage renal disease patients on dialysis.^{121,122} Vascular calcification results in hypovascular tissue, fibrosis, and dermal necrosis, most often in the lower extremities.¹²³ A mortality rate of 60%–80% is reported and is most often the result of septic complications of calciphylaxis wounds.¹²⁴

HBO₂ has been used for calciphylaxis wounds based on the rationale of hyperoxygenating ischemic tissue. Multiple case studies and case series have reported healing in previously refractory calciphylaxis wounds after a

course of HBO₂,^{122,125–132} and concomitant use of HBO₂ and thiosulfate has been advocated.^{131,132} Despite the fact that there are no high-quality studies that compare HBO₂ to a control group, it has been used as a treatment of last resort after other standard therapies have failed. Logic dictates that earlier use of HBO₂ would be more successful than later use of HBO₂.

Scleroderma

Scleroderma is an autoimmune connective tissue disease that affects the hands, feet, and face. Abnormal thickening of the skin is caused by overproduction of collagen and subsequent damage to smaller arteries, resulting in local tissue hypoxia.¹³³ HBO₂ is thought to improve healing by overcoming tissue hypoxia,^{32,134,135} although the effects of collagen modulation with HBO₂ are unclear. Systemic scleroderma is an autoimmune disease, and HBO₂ has been shown to play a role in minimizing the proliferation of damaging lymphocytes and modulating the biology of cytokines and inflammatory mediators.^{136,137}

The evidence for the use of HBO₂ in the treatment of scleroderma relies on case reports of refractive scleroderma wounds that have healed with HBO₂.^{138–145} Patient selection should rely on clinical judgement as to the likelihood that HBO₂ can alter the trajectory of the scleroderma ulcer.

Graft-versus-host disease (GvHD)

Allogeneic stem cell transplantation in the treatment of hematopoietic and lymphatic malignancies may result in cutaneous complications of GvHD. The most common manifestations of GvHD are skin ulcers resulting from dermal/subcutaneous endothelial damage and micro-angiopathy.^{146–148} HBO₂ results in neovascularization and collagen deposition at the site of hypoxic tissue such as those in GvHD.^{24,53} HBO₂ may also play a role in immune modulation.^{136,137}

The evidence for use of HBO₂ in GvHD relies on animal studies and case report data.^{149,150} Patient selection should rely on clinical judgement and may benefit from objective assessments of tissue perfusion and hypoxia to determine whether treatment is appropriate for individual patients.

Pyoderma gangrenosum (PG)

PG is a rare neutrophilic dermatosis that affects the skin and subcutaneous tissues. Histopathologic characteristics include edema and neutrophil infiltrates of small and medium-sized vessels. Thrombosis of these vessels results in

surrounding hemorrhage. The neutrophil infiltration and inflammation can result in abscess formation with resultant liquefaction of the tissue.¹⁵¹

HBO₂ has been utilized for decades for the treatment of PG,^{152–154} overcoming hypoxia and providing an anti-inflammatory effect. A 2007 review provided a comprehensive listing of positive and negative case studies and concluded that HBO₂ was an effective treatment option for cutaneous ulcers related to PG, resulting in decreased pain and increased quality of life.¹⁵³ HBO₂ may be considered for PG ulcers refractive to conventional therapies.

Sickle cell disease (SCD)

SCD is characterized by red blood cells that deform and take a sickled shape, impairing binding of oxygen, compromising circulation, producing ischemia, and causing anemia.¹⁵⁵ Approximately 2.5% of patients with SCD will develop a lower extremity ulcer.¹⁵⁶ HBO₂ has been shown to reduce the percentage of circulating sickled cells after a hyperbaric exposure to 2 ATA.^{157,158}

There is a single case report describing the use of HBO₂ for two patients with SCD-related cutaneous wounds with a 50% response rate.¹⁵⁹ There are both positive and negative case reports for the use of HBO₂ in the treatment of pain crises,^{158,160,161} priapism,¹⁶² and central retinal artery occlusion¹⁶³ complicated by SCD. There is insufficient evidence to support the routine use of HBO₂ in the treatment of SCD ulcers, although it may be useful for non-cutaneous manifestations of SCD.

Venous stasis ulcers (VLUs)

VLUs account for 90% of ulcers of the lower extremity and are the result of uncontrolled leg edema. Edema decreases perfusion as intra-compartment pressures rise and compromise capillary flow. Compression therapy is the mainstay of therapy, reducing edema through augmentation of the calf pump and directly increasing extraluminal pressure. With uncontrolled edema, oxygen diffusion from capillary beds is reduced as the distance between capillaries increases as a result of cellular tumescence.

HBO₂ has been found to reduce wound surface area following therapy in two randomized, sham controlled trials, but neither showed an improvement in healing rates.^{164,165} A third study did show statistically significant wound healing with HBO₂.¹⁶⁶ There is insufficient evidence to support the routine use of HBO₂ in the treatment of VLUs.

Conclusion

The use of HBO₂ for chronic, problem wounds is best defined for DFUs, but there is a sound fundamental basis for its use for some other chronic wound types. There is a lack of high-quality clinical evidence for non-DFU indications however, and providers must utilize clinical judgement to decide whether the reason for wound healing failure can be overcome with HBO₂. Large clinical trials are unlikely to be successful given the rarity of these conditions, but participation in a research registry may allow pooled data to demonstrate efficacy of HBO₂.

Disclosure

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