

The following are explanations with references of the UHMS approved indications for Hyperbaric Oxygen:

AIR OR GAS EMBOLISM

Air or gas embolism occurs when gas bubbles enter arteries, veins and/or capillaries. This results in reduced blood flow and poor oxygen delivery to the areas supplied by the affected circulation. If not fatal, gas embolism can result in severe, long-standing and irreversible physical and emotional disabilities. There can be weakness or paralysis in the limbs; vision can be impaired or absent; brain, heart, lung and other organ damage may occur. Limited use of remaining functions can be sufficiently severe that total disability results. Those who do not die may be limited to walking with canes, crutches or walkers. Those more severely disabled may be wheelchair confined or bedridden. These outcomes may be permanent and may severely impact quality of life. Maximal medical treatment of the condition is necessary to ensure the best possible degree of recovery from this potentially disastrous problem.

Hyperbaric oxygen has been shown to reduce the size of bubbles obstructing circulation. The increased pressure in the hyperbaric chamber reduces bubble size and drives the remaining gas into physical solution, while the high oxygen pressure washes out inert gas from the bubble. When bubbles are smaller or resolved, blood flow resumes. Poorly oxygenated tissues then receive higher levels of oxygen delivery. Another problem in gas embolism is that vessels obstructed by bubbles may leak fluid into surrounding tissues, resulting in swelling. Such swelling can further reduce tissue blood flow. When flow is restored, the local swelling will subside with resultant improvement in circulation and oxygen supply. Finally, the high levels of oxygen provided in the hyperbaric chamber have the potential to immediately restore cellular oxygen levels while blood flow impairment and tissue swelling are being corrected.

Hyperbaric oxygen treatment is the primary treatment for gas embolism and a major review of reported cases clearly indicates superior outcomes with its use compared to non-recompression treatment.

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CARBON MONOXIDE

Carbon monoxide (CO) is a colorless, odorless gas produced as a byproduct of combustion. Poisoning occurs by inhalation, either accidentally or intentionally (suicide attempt). CO poisoning is responsible for an estimated 40,000 emergency department visits and 1,000 accidental deaths in the United States annually. Approximately 5-6% of patients evaluated in emergency departments for CO poisoning are treated with hyperbaric oxygen (HBO₂).

CO binds to hemoglobin in red blood cells at the sites usually utilized to carry oxygen to tissues. Oxygen, and especially hyperbaric oxygen, accelerates the clearance of CO from the body, thereby restoring oxygen delivery to sensitive tissues such as brain and heart. This has traditionally considered to be the mechanism of benefit of HBO₂. However, research published in the past few years has demonstrated a number of other mechanisms of toxicity from CO. Blood vessel (vascular) injury from CO has been demonstrated to result from CO-induced production of nitric oxide-derived

oxidants and cellular injury from activated white blood cells (neutrophils). CO also causes direct central nervous system cellular injury through mechanisms that include disturbance of energy metabolism and intracellular production of oxygen free radicals. In animal experiments, hyperbaric oxygen, but not normobaric oxygen (NBO₂), has been demonstrated to block each of these mechanisms of toxicity.

Until ten years ago, the benefit of hyperbaric oxygen treatment of CO poisoning was demonstrated by comparing the clinical experience at institutions where HBO₂ was used with that at facilities where it was not available. Since 1989, six randomized prospective trials have been reported comparing HBO₂ with NBO₂ treatment of acute CO poisoning. Of these, three demonstrate improved patient outcomes with hyperbaric oxygen, two report no difference between the two therapies, and one remains blinded with regard to the treatment administered. A full listing of the investigations, as well as a discussion of the study designs and findings, can be found in the *UHMS Hyperbaric Oxygen Therapy Committee Report* (available for purchase through this web site).

The UHMS currently recommends HBO₂ treatment of individuals with serious CO poisoning, as manifest by transient or prolonged unconsciousness, abnormal neurologic signs, cardiovascular dysfunction, or severe acidosis.

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CLOSTRIDIAL MYOSITIS & MYONECROSIS (GAS GANGRENE)

Clostridial myositis and myonecrosis is an acute, rapidly progressive infection of the soft tissues commonly known as "gas gangrene." The infection is caused by one of several bacteria in the group known as "clostridium." While over 150 species of clostridium have been identified, only a few commonly cause gas gangrene. The infection typically spreads from a discrete focus of clostridium within the body. The original source can actually be within the body, as clostridium normally live in the gastrointestinal tract. Alternatively, the infection can originate outside the body, such as when infection results from contamination of wounds during trauma (e.g. motor vehicle accidents).

Gas gangrene infection is severe and can advance quickly. Besides replicating and migrating, the organisms which cause gas gangrene produce poisons known as exotoxins. Exotoxins are capable of liquefying adjacent tissue and inhibiting local defense mechanisms which might normally contain a less virulent infection. As such, the advancing infection of gas gangrene may simply destroy healthy tissue in its path and spread over the course of hours.

Clostridium bacteria are "anaerobic," meaning that they prefer low oxygen concentrations to grow. If clostridium are exposed to high amounts of oxygen, their replication, migration, and exotoxin production can be inhibited. This is the rationale for the use of hyperbaric oxygen in the treatment of gas gangrene. Repeated treatment in the hyperbaric chamber has the potential to slow the progress of the infection while the two primary therapies, antibiotics and surgical resection of infected tissue, control it.

The advantages of hyperbaric oxygen treatment in gas gangrene are two-fold. First, it may be life-saving because exotoxin production is rapidly halted and less heroic surgery may be needed in gravely ill patients. Second, it may be limb and tissue-saving, possibly preventing limb amputation that might otherwise be necessary.

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CRUSH INJURY

Crush injuries occur when body tissues are severely traumatized such as in motor vehicle accidents, falls, and gun shot wounds. These injuries frequently occur in the extremities. When crush injuries are severe, the rate of complications such as infection, non-healing of fractures, and amputations range up to 50%.

When used as an adjunct to orthopedic surgery and antibiotics, hyperbaric oxygen (HBO₂) therapy shows promise as a way to decrease complications from severe crush injuries. HBO₂ increases oxygen delivery to the injured tissues, reduces swelling and provides an improved environment for healing and fighting infection.

Hyperbaric oxygen treatments should be started as soon after an injury as possible. They are usually continued for 5 to 6 days. A number of related conditions, including compartment syndromes, thermal burns, and threatened replantations are also benefited by hyperbaric oxygen, as discussed in other sections in this site.

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DECOMPRESSION SICKNESS or ILLNESS and ARTERIAL GAS EMBOLISM

When scuba diving, additional oxygen and nitrogen dissolve in body tissues. The additional oxygen is consumed by the tissues, but the excess nitrogen must be washed out by the blood during decompression. During or after ascent this excess nitrogen gas can form bubbles in the tissues, analogous to the carbon dioxide bubbles that form when a carbonated beverage container is opened. These bubbles may then cause symptoms that are referred to as decompression sickness ("DCS" or "the bends"). Trapping of gas within the lungs during ascent, either because the lung is diseased or because of breath-holding, can cause bubbles to be forced into the bloodstream ("arterial gas embolism" or "AGE"), where they can block the flow of blood or damage the lining of blood vessels supplying critical organs such as the brain. AGE can also occur in non-divers, due to entry of air into the body, such as during medical diagnostic or therapeutic procedures. Symptoms of DCS or AGE can include joint pain, numbness, tingling, skin rash, extreme fatigue, weakness of arms or legs, dizziness, loss of hearing, and in serious cases, complete paralysis or unconsciousness.

Emergency treatment of DCS or AGE includes administration of oxygen and measures to maintain adequate blood pressure, such as lying the patient down and fluid (either oral or intravenous, depending upon availability and severity of the illness). Definitive treatment for DCS or AGE is administration of 100% oxygen at increased atmospheric pressure in a hyperbaric chamber (typically at a pressure 2-3 times greater than normal atmospheric pressure).

While some delay in transporting a patient to a hyperbaric chamber is usually unavoidable, the success in relieving symptoms is greater if the treatment is administered within a few hours after the onset of symptoms. Some improvement might be expected, particularly in mild cases, even after a day or more of delay.

The vast majority of cases respond satisfactorily to a single hyperbaric oxygen treatment. Sometimes, repetitive treatments are recommended until no further improvement can be observed. A small minority of divers with severe neurological injury may require 15-20 repetitive treatments. The success of hyperbaric oxygen treatment for DCS or AGE has borne the test of time, and continues to be the standard of care for the treatment of these disorders.

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ENHANCEMENT OF HEALING IN SELECTED PROBLEM WOUNDS

Problem wounds are those which fail to respond to established medical and surgical management. Such wounds usually develop in compromised hosts with multiple local and systemic factors contributing to inhibition of tissue repair. These include diabetic feet, compromised amputation sites, nonhealing traumatic wounds, and vascular insufficiency ulcers (ulcers with poor circulation). All share the common problem of tissue hypoxia (low tissue oxygen level, usually related to impaired circulation).

Diabetic foot wounds are one of the major complications of diabetes and an excellent example of the type of complicated wound which can be treated with hyperbaric oxygen. Fifty percent of all lower extremity amputations in the United States are due to diabetes, at a cost of more than one billion dollars per year. It is well known that many diabetics suffer circulatory disorders that create inadequate levels of oxygen to support wound healing.

Hyperbaric oxygen therapy is a treatment in which patients receive high concentrations of oxygen under pressure in order to increase the oxygen level in the blood and tissues. The elevation in tissue oxygen which occurs in the hyperbaric chamber induces significant changes in the wound repair process that promote healing. When hyperbaric treatment is used in conjunction with standard wound care, improved results have been demonstrated in the healing of difficult or limb threatening wounds as compared to routine wound care alone.

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EXCEPTIONAL BLOOD LOSS - ANEMIA

For purpose of consideration of the use of hyperbaric oxygen (HBO₂) therapy, exceptional blood-loss anemia is by definition loss of enough red blood cell mass to compromise sufficient oxygen delivery to tissue in patients who cannot be transfused for medical or religious reasons. Medical reasons may include the threat of blood product incompatibility or concern for transmissible disease. Religious beliefs may prohibit the receipt of transfused blood products.

Red blood cells (RBCs) contain the respiratory pigment hemoglobin (Hb). Hemoglobin has the powerful ability to pick up oxygen as RBCs pass through the blood vessels of the lungs. Hemoglobin then has the equally powerful ability to off-load oxygen in the tissues of the body's organ systems. If plasma were the only vehicle to deliver dissolved oxygen, each 100 ml of blood flowing to an organ system would carry only 0.3 ml of gaseous oxygen. The consumption of oxygen by human tissues far exceeds this. For instance, the kidney extracts approximately 2 ml of oxygen for every 100 ml of blood which circulates through it. From the same 100 ml of blood, the brain extracts approximately 6.5 ml and the heart 10.5 ml of oxygen.

In most instances, humans average 15 grams of hemoglobin per 100 cc of blood. Each gram of hemoglobin transports 1.34 ml of oxygen. This is in addition to the oxygen carried by plasma. So, 100 ml of blood, by containing 15 grams of hemoglobin, can carry approximately 20 ml of gaseous oxygen (1.34 ml X 15 g Hb = 20 ml of oxygen).

In the 1960s, the Dutch thoracic surgeon Boerema demonstrated that one could exchange transfuse piglets with a simulated plasma mixture of buffered normal saline (Ringer's Lactate solution), dextrose and dextran. In this process, blood was removed from the blood vessels and the substitute liquid (without hemoglobin) replaced. He then pressurized the piglets in a hyperbaric chamber while the animals breathed 100% oxygen. By the trick of pressurization, enough oxygen could be dissolved in the simulated plasma mixture to supply tissue oxygen requirements. This was enough to adequately sustain the animal, as evidenced by the fact that the animals survived and could be brought out of the chamber to be successfully re-exchange transfused with their previously extracted blood.

As hyperbaric oxygen (or for that matter normobaric oxygen) administered for long periods can become toxic, intermittent administration of HBO₂ is essential. This point has been demonstrated clinically by the American thoracic surgeon, George Hart. In 1974, he reported a series of 26 severe blood loss patients who were treated with HBO₂ as an alternative to otherwise disallowed red blood cell transfusion. The survival rate was 70%.

Alternative approaches include use of fluorocarbons or stroma-free hemoglobin. While potentially promising, these treatment solutions still pose uncertainties for their potential ability to unfavorably alter the immune system. While erythropoietin may be used to stimulate the bone marrow to produce RBCs, HBO₂ therapy only complements its use in exceptional blood-loss anemia.

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INTRACRANIAL ABSCESS

Abscess formation in the brain can be a devastating complication of sinus infections or bone infections (osteomyelitis) of the skull. Occasionally, abscesses are seeded from infection occurring in other parts of the body. Brain abscesses are frequently multiple.

One of the problems in treatment in treatment of brain abscesses relates to the fact that surgically drainage of their contents is often required for cure. Unfortunately, normal brain tissue surrounding the abscess may be unavoidably damaged by such surgery. Fine needle aspiration of the abscesses is being performed with greater frequency to avoid this problem.

Antibiotics may not penetrate well into brain abscesses. Furthermore, white blood cells, which kill infecting bacteria, may not have enough oxygen to effectively eliminate the infection when functioning deep in the abscess at a distance from their normal blood supply. It is well known that

white blood cells require a minimum level of oxygen to kill bacteria.

Most intracranial abscesses are caused by with anaerobic bacteria (bacteria that function optimally in low oxygen concentrations). Hyperbaric oxygen raises the environmental oxygen level in the region of the abscess, exposing the bacteria to levels which may inhibit or kill them, as well as providing sufficient oxygen for white blood cells to exercise their killing power.

The average mortality from intracranial abscess reported in six large series was 20% when hyperbaric oxygen (HBO₂) was not used. Among the 48 known cases treated with HBO₂ to date, the mortality has been only 2%. Additionally, most of the patients treated with hyperbaric oxygen have returned to their regular daily activity after recovery, with less apparent brain damage. Therapy with HBO₂ carries minimal risk, so the risk-benefit ratio is not arguable.

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NECROTIZING SOFT TISSUE INFECTIONS

A number of types of infections of soft tissue may benefit from adjunct treatment with hyperbaric oxygen and are included in the category of "necrotizing soft tissue infections." Names of such clinical syndromes include crepitant anaerobic cellulitis, progressive bacterial gangrene, necrotizing fasciitis, and nonclostridial myonecrosis. Gas gangrene (Clostridial myositis and myonecrosis) is a separate entity and is reviewed elsewhere in this site.

Necrotizing soft tissue infections may result from either a single strain or a mixed population of bacteria, typically occurring after trauma, surgery, and/or around foreign bodies. The individual affected by such infections is frequently compromised by conditions such as diabetes or vascular disease.

In addition to pre-existing host compromise, necrotizing soft tissue infections themselves may induce conditions adverse to control of the infection by normal host defense mechanisms. The infections commonly lower tissue oxygen levels, impairing the ability of the white blood cells (neutrophils) to fight infection. Toxins produced by bacteria involved may also inhibit neutrophil activity.

The primary treatments for necrotizing soft tissue infection are surgical excision of infected tissue and administration of appropriate antibiotics. In selected cases, addition of hyperbaric oxygen therapy may be both lifesaving and cost effective. Hyperbaric oxygen may be beneficial in several ways. Some of the bacteria involved in necrotizing soft tissue infections are "anaerobic," growing most rapidly in a low oxygen environment. In the hyperbaric chamber, tissue oxygen levels may be raised sufficiently to inhibit bacterial growth. In addition, hyperbaric oxygen treatment may enhance the ability of neutrophils to kill bacteria, by a number of different mechanisms.

The use of hyperbaric oxygen for treatment of necrotizing soft tissue infections should be individualized. In specific instances where risk of morbidity and mortality are high, adjunct hyperbaric oxygen therapy should be considered.

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REFRACTORY OSTEOMYELITIS

Osteomyelitis is an infection of the bone. Refractory osteomyelitis is a bone infection which has not responded to appropriate treatment. Hyperbaric oxygen increases the oxygen concentration in infected tissues, including bone. Hyperbaric oxygen directly kills or inhibits the growth of organisms which prefer low oxygen concentrations (strict anaerobes). These effects occur through the oxygen-induced production of toxic radicals or through an indirect effect mediated through the white blood cells (polymorphonuclear leukocytes).

Conversely, hyperbaric oxygen has no direct effect on organisms which prefer high oxygen concentrations (aerobes). In fact, hyperoxic conditions may induce aerobic organisms to produce increased concentrations enzymes protective against oxygen radicals (e.g. superoxide dismutase). When hyperbaric oxygen increases the oxygen tension in infected tissue, however, the oxygen-dependent killing mechanisms of the polymorphonuclear leukocyte are provided sufficient oxygen to function. Thus, hyperbaric oxygen treatment provides the necessary substrate (oxygen) for the killing of aerobic organisms by the polymorphonuclear leukocyte.

Hyperbaric oxygen also augments the efficacy of bacterial killing by certain antibiotics (aminoglycosides, vancomycin, quinolones and certain sulfonamides). Hyperbaric oxygen provides adequate oxygen for fibroblast activity, cells which promote healing in hypoxic tissues. Finally hyperbaric oxygen prevents polymorphonuclear leukocytes from adhering to damaged blood vessel linings. This decreases the degree of inflammation which may accompany the surgical treatment of refractory osteomyelitis.

Hyperbaric oxygen is used clinically for the treatment of refractory osteomyelitis as noted above. Hyperbaric oxygen is adjunctive therapy and is used with appropriate antibiotics, surgery and nutrition. There are open, patients used as there own controls and randomized clinical studies supporting the use of HBO for the treatment of refractory osteomyelitis.

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HYPERBARIC OXYGEN TREATMENTS FOR COMPLICATIONS OF RADIATION THERAPY

Cancer treatment has improved significantly over the past decade. Although cure of the cancer is still the highest priority of treatment, cancer specialists have come to recognize the ever-increasing importance of quality of life to the cancer survivor. One-half of the estimated 1.2 million new cases of invasive cancer will receive radiation therapy as a part of their cancer treatment. Side effects of this therapy can be very toxic, especially when combined with chemotherapy. Some people are more sensitive to radiation damage than others, and there are no reliable tests available as yet to identify those patients who will experience the worst side effects. Radiation doses must be adequate to control the cancer; otherwise, there is no purpose in treating the patient. Most radiation cancer specialists or oncologists design their treatment protocols to give the best dose to control the tumor and still have no more than 5% of patients develop severe reactions to treatment.

Radiation side effects are generally divided into two categories. First, there are those that happen during or just after the treatment, called acute reactions. Second, there are those that happen months or even years after the treatment, called chronic complications.

The acute side effects almost always resolve with time and are treated in such a way as to address the patient's symptoms. For example, when a patient has a cancer of the mouth or throat, it becomes very difficult for the patient to eat during and just after treatment because the lining of the mouth and throat becomes raw and painful. The cells which make up the linings of the gastrointestinal tract are sensitive to radiation. Both cancer cells and the cells that line the gastrointestinal tract have a high rate of growth, and this rapid growth rate makes them more sensitive to radiation damage. Fortunately, the normal tissue cells have excellent repair abilities and within a few weeks after the completion of radiation, this damage is repaired. In the meantime, the patient is supported with pain medicine and supplemental nutrition.

Unfortunately, chronic complications often may not get better with time and are likely to get worse. Almost all chronic radiation complications result from scarring and narrowing of the blood vessels within the area which has received the treatment. If this process progresses to the point that the normal tissues are no longer receiving adequate blood supply, death or necrosis of these tissues can occur. In the past, a severe level of necrosis would require surgical removal of the damaged tissue. This would be a devastating blow for a patient whose cancer has been cured. For example, though it occurs rarely, a patient who has had cancer of the voice box cured might require the removal of the voice box due to radiation damage. Chronic radiation damage is called "osteoradionecrosis" when the bone is damaged and "soft tissue radionecrosis" if it is muscle, skin or internal organs which have been damaged by the radiation.

Since the 1970's, surgeons of the head and neck region have come to recognize the value of hyperbaric oxygen treatments in treating damage of the jaw bone due to radiation. Hyperbaric oxygen has had some of its most dramatic successes in treating or preventing damage to the jaw bone as a result of radiation treatments. It has now also been applied to damage of the brain, damage of muscle and other soft tissues of the face and throat, damage to the chest wall, abdomen and pelvis as a result of radiation treatment. Papers in medical journals also report success in treating damage to the bladder and intestines due to radiation. The high dose oxygen provided in the hyperbaric chamber is carried in the patient's circulation to the site of injury to be available for repair of the damage done by the narrowing and scarring of the blood vessels. Each treatment typically takes one to two hours, and usually 30-40 daily treatments are needed for healing radiation damage.

Most insurance companies, including Medicare, will provide coverage to pay for hyperbaric treatments for chronic radiation injuries.

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SKIN GRAFTS AND FLAPS (COMPROMISED)

Reconstructing complex wounds is accomplished by shifting or transferring tissues to the wound from a different part of the body. A "skin graft" is the transfer of a portion of the skin (without its blood supply) to a wound. A "flap" consists of one or more tissue components including skin, deeper tissues, muscle and bone. Flaps are transferred with either their own, original blood supply (pedicle flap) or with detached blood vessels which are attached at the site of the wound (free flap). Skin grafts survive as oxygen and nutrients diffuse into them from the underlying wound bed. Long-term survival depends on a new blood supply forming from the wound to the graft. When the wound bed does not have enough oxygen supplied to it, the skin graft will at least partially fail. Common causes for this are previous radiation to the wound area, diabetes mellitus, and certain infections. In these situations, the availability of oxygen in the wound bed can be increased with hyperbaric oxygen therapy (HBO₂) in preparation for skin grafting. Additionally, HBO₂ can be used after skin grafting to increase the amount of the graft that will survive in these compromised settings. Flaps also require oxygen and nutrients to survive. The outer, visible portion (usually skin) is furthest from the source of blood supply for the flap. This is the area most likely to be compromised by inadequate oxygen. Factors such as age, nutritional status, smoking, and previous radiation result in an unpredictable pattern of blood flow to the skin. If a flap is found to have less than adequate oxygen after it has been transferred, HBO₂ can help minimize the amount of tissue which does not survive and also reduce the need for repeat flap procedures. Partial or complete failure of the wound reconstruction is very difficult for a patient and also very expensive. HBO₂ can help by assisting in the preparation and salvage of skin grafts and compromised flaps.

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THERMAL BURNS

Thermal burn injuries, if not fatal, can cause disastrous long-term physical and emotional disability for the survivor. Especially in closed space fires, thermal and smoke (products of combustion) damage to the lungs can occur, requiring in some cases intubation and use of a mechanical ventilator. Burn injuries characteristically progress to become deeper and more extensive with time. Peak damage occurs within 3-4 days after the initial burn, and can be up to 10 times worse than the initial burn injury. In more severe and/or extensive burns (deep second, third and fourth degree burns), multiple aggressive surgeries are generally necessary to excise the burned tissue and later perform skin grafts to cover these areas. Burn injuries can result in lifelong difficulties, physical limitations, loss of job and employment opportunities, and significant disfigurement as the body heals from the injury. In many cases, the burn victim's life is radically changed, literally overnight. The psychiatric adjustments can be overwhelming. When possible, these injuries should be treated in centers that specialize in the management of thermal burns. Adjunctive hyperbaric oxygen (HBO₂) therapy has been shown to limit the progression of the burn

injury, reduce swelling, reduce the need for surgery, diminish lung damage, shorten the hospitalization, and result in significant overall cost savings. These benefits are more apparent if therapy is initiated within 6-24 hours of the burn injury. Ideally, the patient should have 3 sessions in the first 24 hours, twice daily treatments until the process stabilizes, then continued therapy as indicated for healing enhancement and to support grafted areas. Indications for HBO₂ therapy typically include deep second-degree and third-degree burns that involve greater than 20% of the total body surface area, and less extensive burns that involve the face, hands or groin area. Best results are realized when HBO₂ is used as an integral part of an aggressive multidisciplinary approach to the management of this potentially fatal injury. HBO₂ is a very safe therapy even in seriously injured patients when administered by those thoroughly trained in HBO₂ therapy in the critical care setting and with appropriate monitoring precautions.

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