

Why hyperbaric oxygen therapy may be useful in treating crush injuries and skeletal muscle-compartment syndrome

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As an actively practicing orthopedic surgeon and one convinced of the value of hyperbaric oxygen (HBO₂) for specific orthopedic-related conditions, I am frustrated that my orthopedic and trauma surgeon colleagues have not embraced this modality for crush injuries and compartment syndromes.

I am not without experience in managing orthopedic trauma. I was the orthopedic surgeon coordinator of our hospital's level 2 trauma center for 10 years, and an attending orthopedic staff physician/resident mentor for one of Los Angeles County's most active trauma centers. In addition, I provided orthopedic care for the victims of the 1999 Turkey and the 2010 Haiti earthquakes.

It is my opinion that the problem of underutilization of HBO₂ for trauma is not just because of surgeons, but unfortunately, the HBO₂ community is equally responsible. There is much interest (and government-generated funding) in mitigating injury from trauma. All abound with impressive acronyms such as CWIP (Combat Wound Initiative Program), CCC (Combat Casualty Care) initiative, IMCWLS (Interservice Military Complex Wound and Limb Salvage) Center, LEAP (Lower Extremity Assessment Project), DCO (Damage Control Orthopedics, and more. It is a paradox that all seek to improve trauma care and lessen injury, but none consider HBO₂ in their evaluation and treatment study limbs of their research.

To further demonstrate the need to investigate the role of HBO₂, the "first hit" (initial trauma) and "second hit" (surgical procedures and sepsis) concept of damage control include hypoxia [of injured tissue] as an element of each limb of the "hit." Hyperbaric oxygen excels in improving tissue hypoxia, but appears to be totally excluded in any of the limbs of studies by the above groups.

When I confront orthopedic surgeon colleagues about using HBO₂ for managing severe orthopedic trauma, their responses are uniformly smug in deprecating the role of HBO₂. They appear to accept disconcerting complication rates (which are summarized in the next paragraph) as acceptable for their trauma patients.

They always end their caveats with comments like: "who needs it"; "there is no evidence to support its use"; "no randomized control studies are available"; "our patients are too sick to be moved to a chamber"; and "even if we wanted to use HBO₂, chambers are not available."

The following are some of the disconcerting statistics from a review of the trauma literature over the past two years where conventional (*i.e.*, without the use of HBO₂ as an adjunct to management) care was given for severe traumatic injuries. The citations in parentheses are included in an abbreviated format.

1. Global War on Terrorism: Complications in patients where internal fixation of long bone fractures and an amputation are required had an infection rate of 89 percent (J Bone Jt Surg, 2012; 92:2312).
2. Traumatic amputation heights (*i.e.* need for amputation revisions) increased in 30 percent of patients and required a mean of 4.1 debridements (Orthop Today, 2010; Oct, p. 15).
3. High risk patients with open fractures had a 31.6 percent complication rate and those with a hyperglycemic index >3.0 had a complication rate of 64 percent (J Bone Jt Surg, 2010; 92:2247)
4. LEAP Study (J Bone Jt Surg, 2010; 92:2852)
 - 85% of 520 patients with severe lower extremity trauma had complications;
 - 50% of 149 patients who had amputations for severe trauma had a wound infection and/or necrosis;
 - 29.8% of these patients required re-hospitalizations;
 - 14.5% of the amputations required revisions;
 - 6.5 percent of the amputations were not fully healed at 24 months;
 - Lifetime costs (including prostheses) were three times greater for patients with amputations versus those who had limb salvage;
 - With regard to managing the soft tissue envelope, a 44 percent complication rate was observed with rotational flaps and 23 percent rate with microvascular free flaps;
 - Infections rates were 69 percent when bone coverage was not achieved in less than 10 days after injury; if coverage was achieved in less than 10 days, the rate was 18 percent; and if the wounds was allowed to heal by secondary intention, infection occurred in 53 percent of the wounds;

5. The prognosis for severe type 3 [Gustilo] open fractures of the tibial shaft remains guarded; outcomes are often determined by psychosocial variables (J Am Acad Orthop Surg, 2010, 18:108)

6. Cost savings to decrease wound debridements from a mean of 3.5 to 2.5 would result in 2.2 million dollars saving a year for a single military facility (Mil Med, 2010; 175:18)

How can any trauma and/or orthopedic surgeons be satisfied with these statistics? How can they continue to deny the potential benefits of HBO₂ or not even appreciate its well-documented mechanisms that can mitigate the pathophysiology of crush injuries and compartment syndromes? Unquestionable physiological evidence demonstrates the ability of HBO₂ to increase tissue fluid oxygenation tenfold, reduce edema 20 percent, increase oxygen diffusion distances threefold, upregulate growth factors, provide an environment favorable for fibroblast function, support neutrophil oxidative killing, augment the function of several antibiotics and have cidal and static effects on bacteria. How can the mission statement of the CWIP include employing "...state-of-the-art care via targeted clinical and translational research using advanced technologies..." and not consider using HBO₂ in any of their research?

The other problem lies, in my opinion, with our HBO₂ community. Collectively, that is from the Hyperbaric Oxygen Therapy Committee Report and Medicare reimbursement directives, there are 17 "approved" conditions for treatment with HBO₂. Fourteen fit into the category of life-, limb- or acute tissue-threatening indications, while only three (diabetic foot wounds, refractory osteomyelitis and radiation injury) are non-urgent, generally chronic, stable conditions. Unfortunately, only a small proportion of the approximately 1,000 clinical hyperbaric units in the United States are equipped, staffed and willing to handle the 14 acute, usually emergency, conditions of which crush injuries and compartment syndromes are included.

To further compound the problem, Medicare and many other third-party payers do not reimburse for inpatient HBO₂ services. They consider the use of hyperbaric oxygen as a component of the DRG (Diagnostic Related Group). Thus, there is a great disincentive to not use HBO₂ for crush injuries and compartment syndromes as well as the other acute indications for HBO₂.

Is there any solution to this problem? Acting as an individual, I contacted a ranking Navy Medical Corp Admiral who was an orthopedic surgeon. I was armed with the information that an HBO₂ chamber manufacturer had donated seven HBO₂ chambers to our military

service and had them transported to Iraq. At the time of my conversation, six remained stored in a warehouse in Baghdad while the seventh had been made operational for possible diving accidents that our troops might incur from operations in the Tigris-Euphrates River. I described the indications for using HBO₂ applicable to severe traumatic injuries. The admiral's response (through an aide) was basically this: Unless he received a request for HBO₂ from the on-scene commanders, he could not endorse its use.

Obviously, our education of trauma professionals and orthopedic surgeons is grossly inadequate. From the above experience, my recommendations are as follows:

First, our hyperbaric leadership needs to be more proactive in educating the "movers and doers" of the acronymic named organizations previously mentioned and in encouraging them to use HBO₂ in limbs of their studies. Obviously, a single individual does not carry the weight of a scientific organization, as my experience noted above demonstrates.

Second, the physician staffs of HBO₂ units that are willing and equipped to handle the acute indications for HBO₂ should be encouraged to foster relationships with their trauma and orthopedic surgeons. This has worked well for me and my hyperbaric staff physicians in our community, which is only microcosm of the entire spectrum of trauma. We receive almost weekly referrals for HBO₂ treatments from our colleagues for their patients with severe wounds.

Third, HBO₂ organizations need to lobby our legislatures to correct the enormous inequity of not providing reimbursement for the in-hospital patients who need HBO₂ for one or more of the 14 acute conditions. A two-tiered certification process may become necessary to distinguish those facilities that treat only patients with non-emergency indications and those that are full-service 24/7 providers. This would be expected to culminate in appropriate reimbursements for each of the types of service provided.

Unfortunately as this editorial shows, hyperbaric oxygen is woefully neglected as an adjunct for managing crush injury and skeletal muscle-compartment syndromes. Strong arguments for its use based on evidenced-based information and how hyperbaric oxygen mitigates the pathology of these conditions exists. At the minimum, hyperbaric oxygen therapy deserves to be included as a limb in any comparative effectiveness research study that evaluates outcomes for severe injuries. It is my opinion that hyperbaric oxygen is a valuable adjunct for improving outcomes in these life- and limb-threatening injuries. ■