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Hyperbaric Oxygen as an Intervention for Managing Wound Hypoxia: Its Role and Usefulness in Diabetic Foot Wounds

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ABSTRACT

Few topics in diabetic wound management generate as much ''heated'' discussion as hyperbaric oxygen (HBO). Hyperbaric oxygen is an intermittent inhalation therapy in which the patient breathes oxygen at greater than 1 atm of pressure. This requires placement of the patient into a sealed vessel (chamber) which is capable of withstanding pressurization. This article discusses the role of HBO as an adjunct to the management of diabetic problem foot wounds from evidenced-based, approved (by Medicare) indications and cost-effectiveness perspectives.

Key Words: Diabetic Foot Wounds; Economic Considerations; Hyperbaric Oxygen; Transcutaneous Oxygen Measurements; Wound Hypoxia

INTRODUCTION

Hyperbaric oxygen's (HBO) role in diabetic foot wounds becomes clearly defined if it is considered as one of the options for wound oxygenation in the treatment strategies (see ''The Orthopaedic Surgeon's Role in the Treatment and Prevention of Diabetic Foot Wounds'' in this supplement) for managing problem wounds. Its clinical indication is to improve tissue oxygenation when wound hypoxia interferes with healing. It typically is used as an adjunct to other techniques of improving wound oxygenation. This is especially so when angioplasty or revascularization are not feasible or have failed to improve wound oxygenation sufficiently to support successful wound healing. The Center for Medicare/Medicaid Services (CMS) recognizes six clinical indications for HBO applicable to diabetic foot wounds (Table 1).[9] The sixth listed condition in Table 1, ''nonhealing diabetic foot wound,'' was added to the list in April of 2003.

Correction of wound hypoxia is crucial for wound healing. Juxta-wound oxygen tensions of 30 to 40 mmHg are required for wound healing and infection control.[7,8] Hyperbaric oxygen at normal treatment pressures (2 to 2.4 atm absolute) increases juxta-wound tissue fluid oxygen tensions 10-fold. This is due to the physical movement of oxygen into plasma and tissue fluids in direct proportion to the partial pressure of oxygen in the breathing medium (Henry's Law). In turn, oxygen diffusion through relative barriers such as edema, exudates, cicatrix, and bone is increased threefold. If juxta-wound transcutaneous oxygen tensions increase to over 200 mmHg under HBO conditions and HBO is used as an adjunct to wound management, the positive predictive value for wound healing is 0.88 even if room air measurements are less than 30 mmHg.[14]

EXPERIENCES (EVIDENCE-BASED INDICATIONS)

The question of whether HBO improves wound healing rates and outcomes is controversial. An analysis of 12 reports showed that healing rates in problem diabetic foot wounds improved from 48% to 76% and amputation rates decreased from 45% to 19% when HBO was used as an adjunct for management of hypoxic, problem diabetic foot wounds (Table 2). This analysis showed that the outcomes are remarkably similar whether the studies were randomized control, head-to-head, prospective, or retrospective.

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Table 1: Conditions associated with diabetic foot wounds for which hyperbaric oxygen (HBO) is approved

Condition	ICD-9-CM[a] Code	Comments
1. Progressive necrotizing infections	728.86	Often described as mixed aerobic, anaerobic infections, Meleney's ulcers, necrotizing soft tissue infections, and/or combined synergistic gangrene
2. Chronic refractory osteomyelitis	730.10, 730.19	Defined as osteomyelitis persisting for more than 1 month or recurring after treatment
3. Preservation of compromised skin grafts/flaps	996.52	Excludes artificial skin substitutes; this indication is especially beneficial in ''challenging'' closures/ coverages of hypoxic wounds
4. Acute peripheral arterial insufficiency	444.21, 444.22 and 444.81	Due to thrombosis or emboli; often presents as acute gangrene of the toes and/or forefoot
5. Gas gangrene	040.0	Clostridial myonecrosis; rarely occurs in diabetic foot wounds
6. Nonhealing diabetic foot wound	250.7	Nonhealing $>$ 30 days; Wagner Grade 3 or higher; documented progress within 30 days with HBO

Source: CMS (Center for Medicare/Medicaid Services).
[a] *International Classification of Diseases*, 9th ed, Clinical Modification, Ingenix, Inc. (800-621-8335)

COST-EFFECTIVENESS CONSIDERATIONS

Hyperbaric oxygen treatments are expensive, about $400–$500 a session. Angiogenesis and infection control in the problem wound usually are achieved with 14 to 21 HBO treatments. When chronic refractory osteomyelitis of long bones is present, the number may be increased to 60 treatments. The additional expenses associated with HBO need to be measured against the costs of extended care for a nonhealing wound and limb amputation. The total costs of lower limb amputations including prostheses and rehabilitation for the first 18 months after failed revascularizations were reported to be over $50,000.[10] For a marginal ambulators, which include many diabetic patients with problem foot wounds, a leg amputation may end a patient's ability to live independently. Not only does each year of assisted care cost $30,000 to $60,000, but the consequences of losing a lower limb and being transferred to a new environment can be psychologically devastating. These considerations make HBO a cost-justifiable adjunct for the problem wound that is not healing because of wound hypoxia.

CONCLUSIONS

The importance of perfusion and oxygen for wound healing is indisputable. Wound hypoxia is the major reason problem wounds fail to heal. The foot surgeon can correct deformities. The patient can live with neuropathy. Hyperbaric oxygen corrects wound hypoxia. Once a wound is healed, the metabolic requirements

Table 2: Outcomes of diabetic foot wounds managed with and without hyperbaric oxygen (HBO)

Type of Study/ Author, Year	Patients		Healed (%)		Amputation (%)		Comments
	HBO	No HBO	HBO	No HBO	HBO	No HBO	
Randomized Control Trials							
Abidia, et al.[1] 2001	19	14	13 (68)	4 (29)	—	—	At the 12-week end point of the study, the median wound area decreased 96% in the HBO group vs. 41% in the control ($p = 0.43$)
Thang, et al.[16] 2001	20	12	17 (85)	6 (50)	—	—	Those in HBO group had more severe wounds (Wagner Grade NS, but Strauss Wound Score $p = 0.03$)
							Healing: HBO = 95.6 days; controls 138.1 days, $p = 0.038$
Faglia, et al.[6] 1996	35	33	—	—	3 (8.6)	11 (33%)	Significant improvement in juxta-wound $P_{tc}O_2$'s in the HBO group
Summated Responses:			77%	38%			
Difference (i.e., healing % with HBO — healing % in controls) = 39%							
Head-to-Head Studies							
Britton and Barrie[3] 1987	—	64	—	29 (45)			Standard care without HBO
Wirjosemito,[18] 1992	42	—	35 (83)	—	5 (12)	—	Matched subjects with Britton's study; 5-year follow-up
Summated Responses:			83%	45%			
Difference = 38%							
Prospective Studies							
Wattel, et al.[17] 1990	59	—	52 (88)	—	7 (12)	—	HBO healed group had significantly higher $P_{tc}O_2$'s than the failed group
Baroni, et al.[2] 1987	18	10	16 (89)	2 (11)	0 (0)	4 (10)	Matched retrospective controls; standard diabetic management for both
Summated Responses:			88%	11%			
Difference = 77%							
Retrospective Studies							
Stone, et al.[12] 1995	87	383	63 (72)	203 (53)	24 (28)	179 (47)	HBO-treated patients had more severe wounds (using the Wagner Score)
Oriani, et al.[11] 1990	62	18	59 (95)	12 (67)	3 (5)	6 (33)	Controls refused HBO
Cianci, et al.[4] 1988	39	—	36 (92)	—	3 (8)	—	
Davis,[5] 1987	168	—	118 (70)	—	50 (30)	—	

(*continued*)

Table 2: (*continued*)

Type of Study/ Author, Year	Patients		Healed (%)		Amputation (%)		Comments
	HBO	No HBO	HBO	No HBO	HBO	No HBO	
Strauss, et al.[15] 1985	50	—	44 (88)	—	—	—	
Summated Responses: Difference = 24%			79%	55%			
Summary							
Total	599	534	453/535[a]	256/534	95/510[b]	200/444[c]	
Percent			76	48	19	45	

$P_{tc}O_2$, transcutaneous oxygen measurements.
[a]Patients who received HBO as a limb of the study (Excludes Britton's study).
[b]Patients who received HBO where amputation was an included outcome.
[c]Patients who did not receive HBO where amputation was an included outcome.

around the old wound site are a fraction of what was required for wound healing.[13] This is why HBO can be so useful during the angiogenesis and infection control phases of wound healing, but can be stopped after these effects have been achieved. Hyperbaric oxygen is not in competition with other strategies for wound healing but an adjunct to be used with the specific indication of wound hypoxia that is severe enough to interfere with healing.

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