

# Hyperbaric Oxygenation Accelerates the Healing Rate of Nonischemic Chronic Diabetic Foot Ulcers

A prospective randomized study

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**OBJECTIVE** — To study the effect of systemic hyperbaric oxygenation (HBO) therapy on the healing course of nonischemic chronic diabetic foot ulcers.

**RESEARCH DESIGN AND METHODS** — From 1999 to 2000, 28 patients (average age  $60.2 \pm 9.7$  years, diabetes duration  $18.2 \pm 6.6$  years), of whom 87% had type 2 diabetes, demonstrating chronic Wagner grades I–III foot ulcers without clinical symptoms of arteriopathy, were studied. They were randomized to undergo HBO because their ulcers did not improve over 3 months of full standard treatment. All the patients demonstrated signs of neuropathy. HBO was applied twice a day, 5 days a week for 2 weeks; each session lasted 90 min at 2.5 ATA (absolute temperature air). The main parameter studied was the size of the foot ulcer measured on tracing graphs with a computer. It was evaluated before HBO and at day 15 and 30 after the baseline.

**RESULTS** — HBO was well tolerated in all but one patient (barotraumatic otitis). The transcutaneous oxygen pressure ( $TcPo_2$ ) measured on the dorsum of the feet of the patients was  $45.6 \pm 18.1$  mmHg (room air). During HBO, the  $TcPo_2$  measured around the ulcer increased significantly from  $21.9 \pm 12.1$  to  $454.2 \pm 128.1$  mmHg ( $P < 0.001$ ). At day 15 (i.e., after completion of HBO), the size of ulcers decreased significantly in the HBO group ( $41.8 \pm 25.5$  vs.  $21.7 \pm 16.9\%$  in the control group [ $P = 0.037$ ]). Such a difference could no longer be observed at day 30 ( $48.1 \pm 30.3$  vs.  $41.7 \pm 27.3\%$ ). Four weeks later, complete healing was observed in two patients having undergone HBO and none in the control group.

**CONCLUSIONS** — In addition to standard multidisciplinary management, HBO doubles the mean healing rate of nonischemic chronic foot ulcers in selected diabetic patients. The time dependence of the effect of HBO warrants further investigations.

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Lower-extremity ulcers are responsible for 20% of the hospital admissions of diabetic patients; the incidence of amputation is 6 per 1,000 (1). Foot ulcer represents one of the major causes of lower-extremity injuries in the 220 million people suffering from diabetes worldwide, 2.5% of whom will de-

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**Abbreviations:** HBO, hyperbaric oxygenation;  $TcPo_2$ , transcutaneous oxygen tension.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

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velop a foot ulcer each year (2). Moreover, duration of hospitalization attests to the high morbidity of this condition (3), which has been shown to require as long as ~26 weeks for full recovery (4) despite a multidisciplinary approach (associating glycemia control, daily local care, foot off-loading antibiotic therapy, and surgical revascularization).

The diabetic foot is characterized by sensory, motor, and autonomic neuropathies leading to alteration of pressure distribution, foot deformities, and ulcerations. Metabolic control and infection treatments are of primary importance to control the evolution of the diabetic foot. Hyperbaric oxygenation (HBO) has previously been proposed as an adjunctive treatment for the diabetic foot because it improves in vitro the complex processes underlying healing (5–7). It has also been reported that HBO reduces the incidence of major amputation in diabetic patients with a gangrenous foot (8). The actual value of HBO on diabetic foot healing is, however, still a matter of discussion because conflicting data exist in the literature (9–13) on its true therapeutic effect. The difficulty in controlling the different parameters (metabolic, vascular, infectious, and foot off-loading) involved in the evolution of the diabetic foot and the lack of prospective randomized studies on the effect of HBO on this pathophysiological condition make it difficult to recognize HBO as an incontrovertible treatment.

Recently, Méchine et al. (14) have reported on the effect of HBO on the acceleration of angiogenesis and on a stimulation of neovascularization in an experimental model of wound healing in the rat. On the other hand, Wattel et al. (15) showed that the effectiveness of HBO on healing in nondiabetic patients was dependent on the peripheral arterial disease. Consequently, the purpose of this study was to evaluate the effect of HBO on