Effects of hyperbaric oxygen therapy on perfusion parameters and transcutaneous oxygen measurements in patients with intramedullary nailed tibial shaft fractures

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Lindström T, Gullichsen E, Lertola K, Niinikoski J. Effects of hyperbaric oxygen therapy on perfusion parameters and transcutaneous oxygen measurements in patients with intramedullary nailed tibial shaft fractures. Undersea Hyper Med 1998; 25(2):87–91.—We evaluated the effect of hyperbaric oxygen (HBO₂) therapy on tibialis posterior (TPA), dorsalis pedis (DPA), and sura (TPA+DPA) arterial peak signals, as well as transcutaneous oxygen (Ptco₂) tension and leg skin temperature (T) after intramedullary nailing of tibial shaft fractures. Twenty consecutive patients with closed and simple tibial shaft fractures treated with reamed intramedullary nailing were assigned randomly to HBO₂ or control groups. HBO₂ therapy was given postoperatively at 2.5 atm abs pressure for 90 min daily for a total of five treatments. The first HBO₂ therapy was given 1 h after the operation. In both groups, measurements were performed preoperatively, 30 min and 6 h postoperatively, and on the following 5 days. There was a statistically significant improvement in TPA values in the nailed legs in the HBO₂ treatment group after the first postoperative day, and these values remained at a significantly higher level until the end of the study when compared to the nailed legs in the control group. Further, there was a statistically significant improvement in Ptco₂ values in the nailed legs in the HBO₂ group after the third HBO₂ treatment. However, there were no statistically significant differences in DPA and TPA+DPA values within or between the nailed legs in HBO₂ and control groups. HBO₂ therapy seemed to decrease the skin temperature of the nailed legs, but this alteration was not statistically significant. In addition to the clearly documented advantages in the management of crush injuries and compartment syndromes, HBO₂ therapy has a positive effect on the perfusion parameter (TPA) and Ptco₂ in patients with low energy, intramedullary nailed simple tibial shaft fractures. The improvement in TPA and Ptco₂ values may result from the vasodilatative and edema reductive effect on HBO₂ with concomitant inhibition of inflammatory reactions with slight cooling.

After tibial shaft fracture the cortical blood flow changes from centrifugal to centripetal and the fracture causes markedly activated extraossual circulation, which may alter distal arterial flow patterns in the injured leg (1–3).

Clinical experience has shown intramedullary nailing to be a safe procedure in the treatment of tibial shaft fractures, although damage to the vascular system of bone and elevated intramedullary pressure and temperature have been demonstrated (4–6). Additionally, the fracture and reamed nailing may increase the pressure in the compartments adjacent to the fracture and thus possibly alter the blood flow in the deep arteries distal to the fracture (7,8).

During the past decade, hyperbaric oxygen (HBO₂) therapy has become accepted and recommended in the treatment of various ischemic states, and its benefits are clearly documented in crush injuries and compartment syndromes (9–13).

However, these clinical reports represent studies in a heterogenous variety of critical ischémias and modalities of treatment. Therefore, we designed a standardized, prospective, randomized investigation to delineate the effect of HBO₂ on local perfusion parameters in the lower extremities of otherwise healthy patients undergoing intramedullary nailing due to uncomplicated tibial shaft fracture.

MATERIAL AND METHODS

This study was performed in the Department of Surgery, University of Turku, from September 1994 to December 1996. The study design was approved by the local Ethical Committee and informed consent was obtained from each patient.

After triage in the emergency unit, the clinical status and x-rays of each patient were used to classify the fracture by the AO (Arbeitsgemeinschaft für Osteosynthesefragen)
method and soft tissue injury by a grading system developed by Tscherne and co-workers (14,15) (Fig. 1 and Table 1).

The Hبو group consisted of 10 patients with unilateral, closed tibial shaft fracture. The mean age of the patients was 43 yr (range 15–58 yr). The group included three AOA1, four AOA2, and three AOA3 fractures. Soft tissue injury was minimal in every case (Tscherne 0-1). The patients had no additional injuries and were otherwise healthy (ASA 1).

Ten patients with unilateral and closed tibial shaft fracture were included in the control group. The mean age of the patients was 44 yr (range 34–55 yr). The control group included one AOA1, six AOA2, and three AOA3 fractures, and soft tissue injury was minimal (Tscherne 0-1). As in the Hبو group, the patients were otherwise healthy (ASA 1) and had no other injuries.

Fractures were first treated with a lower extremity split plaster cast with distal fenestrations for preoperative measurements. Thereafter the patients were randomized to Hبو and control groups, and on the following day intramedullary nailing with reaming (Grosse-Kempf, Howmedica, Kiel, Germany) was performed under spinal anesthesia by an experienced traumatologist (E.G.).

Hyperbaric oxygen treatments were given in a multiplace hyperbaric chamber compressed with air at a pressure of 2.5 atm abs. At this pressure, the patients breathed 100% oxygen through a tight-fitting facial mask. The Hبو protocol included 90 min of O₂ breathing once daily, 5 times postoperatively.

The measurements were performed preoperatively without anaesthesia, 30 min and 6 h postoperatively, and on 5 successive postoperative days. In the Hبو group, the measurements were performed 4–6 h after the therapy. Additionally, each patient was evaluated daily for clinical signs, such as pain with passive motion and tenseness of compartments, suggesting compartment syndrome.

Tibias posterior (TPA) and dorsalis pedis (DPA) arterial peak signals were measured with a 10-MHz Doppler probe behind the medial malleolus and intermalleolar space, anteriorly, with a Hadeco ES-1000 SP-II Doppler meter (Arima, Japan). The mean values of 14 consecutively recorded peak signal values were calculated from each TPA and DPA. Transcutaneous oxygen (P tcO₂) tensions were determined from the skin adjacent to the fracture area and the same area from the contralateral leg, at room temperature with a commercially available TINA TCM3 monitor and oxygen electrode (Radiometer, Copenhagen, Denmark). Temperature was measured from the intact skin of the fracture area and corresponding area of the contralateral leg with the MC 8700 two-channel digital thermometer with cutaneous electrode (Exacon, Roskilde, Denmark).

Before each measurement, both legs were elevated to a 20° angle and the blankets removed. The ankles were kept in neutral position during pulse measurements. Skin preparation consisted of shaving, followed by wiping with alcohol and subsequent air drying. The P tcO₂ probe and monitor were calibrated to room temperature and ambient barometric pressure according to manufacturer’s directions. A steady state equilibrium of P tcO₂ occurred after 30 min and that of temperature after 10 min.

The results are expressed as mean ± SEM. Analysis of variance for repeated measurements was used for statistical analysis (16). A P value < 0.05 was interpreted as statistically significant.

**RESULTS**

The postoperative courses of the patients were uneventful. No marked malrotation or diastasis was observed in the postoperative x-rays, nor were there clinical signs suggesting compartment syndrome. The patients were normovolemic during the study period, and hemoglobin and hematocrit remained within normal limits.

The results are represented in Fig. 2. The TPA values in the nailed legs in the Hبو group improved statistically significantly only after the first postoperative day and were statistically significantly higher until the end of the study when compared to TPA values in the controlled nailed legs (P < 0.001). The changes in DPAs and TPA-DPAs were not significant within or between the groups.

**Table 1: Tscherne’s Grading System of Soft Tissue Injuries Associated in Closed Fractures (15)**

<table>
<thead>
<tr>
<th>Grade 0</th>
<th>Injuries with indirect trauma forces with negligible soft tissue damage.</th>
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<td>Grade 1</td>
<td>Injuries caused by lower- or moderate-energy mechanisms and having superficial abrasions or contusions of the soft tissues overlying the fracture.</td>
</tr>
<tr>
<td>Grade 2</td>
<td>Injuries with significant muscle contusion or deep contaminated skin abrasions.</td>
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<tr>
<td>Grade 3</td>
<td>Injuries with extensive crushing or avulsions, arterial disruption or compartment syndrome possible.</td>
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![FIG. 1.—AO fracture classification of simple tibial fractures. Figure from (14). Reprinted with permission.](image-url)
FIG. 2—Measured perfusion parameters during the study period. ■ HBO₂ nailed, ○ control nailed, □ HBO₂ contralateral, ● control contralateral. Mean ± SEM. *P* values refer to analysis of variance for repeated measurements. # = time-related changes within HBO₂ group, *P* < 0.02; ** = intergroup changes, *P* < 0.001.
The PtcO₂ tension values in the nailed legs increased significantly after the third HBO₂ treatment. This improvement was statistically significant between the 2nd and 3rd as well as between the 4th and 5th postoperative day ($P < 0.02$). Therefore, the increase in the PtcO₂ values between the 2nd and 5th postoperative day was statistically highly significant, $P < 0.001$. A slight decrease occurred in the skin temperature values after the second HBO₂ treatment, but this alteration was statistically nonsignificant.

**DISCUSSION**

Tibial shaft fractures with disruption of soft tissues, hematoma, and edema lead to microcirculatory compromise and ischemia in surrounding soft tissues (9). Further, soft tissue injury will result from secondary microcirculatory alterations, which include vasoactivity due to pain perception and the metabolic response to trauma (17).

Several clinical observations suggest that the 10 MHz Doppler probe used in the present study is optimal for superficial artery peak pulse measurements (18). In this paper the TPAs may be decreased due to increased pressure in the deep posterior compartment caused by the fracture. Furthermore, intraosseal bone substance, which was possibly pressed extraosseously via the fracture site during the operation, did not noticeably affect the peak flow values from the posterior tibial artery, as concluded by the stable TPA values pre- and postoperatively in the nailed legs in both groups. Similarly, we assume that the conditions in the anterior tibial compartment remained unchanged, as suggested by the steady DPA values. The positive correlation between compartmental pressure and arterial peak flow values has been discussed comprehensively by Ashton (19).

The HBO₂ exposure protocol introduced in the present study (90 min once a day without air breaks) has been accepted by Strauss (20). It has previously been found that O₂ tension in muscles and subcutaneous tissues returns to normal within 1–2 h after HBO₂ exposures (21). In this study, the measurements were performed 4–6 h after HBO₂ therapy to observe whether HBO₂ therapy has any longacting beneficial effect on the leg perfusion and skin oxygenation.

Hyperbaric oxygen seems an ideal adjunct for the treatment of crush injuries and acute limb ischemias, because its primary effects are hyperoxygenation and concomitant reduction of edema in the muscle compartments via vasoconstriction in arterioles, with unchanged venous outflow and lymph drainage (12,22,23). The present data suggest that HBO₂ had beneficial effects on the arterial circulation in the deep posterior compartment as concluded by the significant improvement of TPA values after the second postoperative day. Conversely, the inability of HBO₂ exposure to alter the DPA values suggests that only minor tissue injury occurred in the anterior compartment.

Transcutaneous oxygen monitoring is a valuable method of estimating response to HBO₂ therapy, and it seems to be a useful method to evaluate the improvement of soft tissue ischemia of the traumatized limb in crush injury (9). Any limitation of local blood flow, for example external compression of vessels, will result in reduced PtcO₂ values (24). In the present study, PtcO₂ values in the nailed legs were possibly decreased as a result of impaired arterial microcirculation in the swollen skin adjacent to the fracture, despite relatively similar TPA+DPA values in the nailed and contralateral legs. However, we suggest that HBO₂ exposure improves local skin circulation in the fracture area, as concluded by the significant improvement of PtcO₂ values in the HBO₂ group after the 2nd postoperative day. The causal relationship between increased TPA values and improved skin oxygenation could not be demonstrated.

Raised skin temperature in the fractured legs may result from increased local arterial circulation due to multiple activation of humoral mediators that participate in the metabolic response to trauma (17). In the present study, local thermal activation was not able to maintain normal superficial circulatory conditions and transcutaneous oximetry values in the controlled nailed group, but HBO₂ treatment seemed to decrease slightly the local skin temperature after the 1st day.

To conclude, increased posterior tibial artery peak signals and PtcO₂ tension values demonstrate improved local soft tissue perfusion and oxygenation due to HBO₂ treatment in nailed simple tibial shaft fractures. This beneficial effect of HBO₂ may be of crucial importance in the adjuvant treatment of severely crushed legs with critical local ischemia.

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**REFERENCES**

HYPERBARIC OXYGEN IN TIBIAL SHAFT FRACTURES
