INTRODUCTION

Multiple-trauma patients with severe injuries commonly suffer a hemorrhagic shock situation with a transient reduction in blood supply. To prevent multiple organ failure and lower the mortality rate these patients require immediate treatment with resuscitation solutions. Although fractures are not an immediate concern, most of these patients sustain fractures, which need attention after the life-threatening situation is stabilized. In general, fractures require an adequate blood supply in order to heal. Traumatic disruption of blood supply and decreased vascularity interfere with bone healing and may result in delayed union or even atrophic non-union. On the other hand, experimentally induced blood loss has been shown to evoke systemic osteogenic responses (1). Therefore, the purpose of the current study was to assess the effect of a transient hemorrhagic shock followed by volume resuscitation on fracture healing. We hypothesized that a transient reduction of blood supply to the fracture site would result in a delay of revascularization and a deterioration of healing.

METHODS

Sixty-three Wistar rats (age: 77 days, weight: 395g) were randomly divided into a control group and two different shock groups. Four animals per group were randomly chosen for euthanasia at day 1, 3, 7, and 14, respectively. Five animals per group were kept for 28 days. Under general anesthesia all rats received a closed fracture of the right hind limb. The fracture was stabilized with a 0.7 mm steel wire drilled into the medullary channel. A second steel wire was inserted into the proximal fragment to maintain rotational stability. The broken fibula was not fixed. Postoperative radiographs confirmed exact pin placement. Catheters were implanted into the external jugular vein and common carotid artery, to facilitate continuous recording of blood pressure and heart rate (Hellige, Germany). In the two shock groups a hemorrhagic shock was induced by blood extraction from the vein until a mean blood pressure of less than 60 mmHg was obtained. The shock situation was maintained for 20 minutes. One group of animals (HES) was resuscitated with an isovolumetric 6% hydroxyethylstarch solution (Fresenius Kabi, Germany). The other shock group (SVR) was resuscitated with a small volume resuscitation (4 ml/kg bodyweight) consisting of 7.2% sodium chloride/6% hydroxyethylstarch solution. Laser Doppler flow measurements (LEA, Germany) were performed to assess changes in vascularity. Measurements were located at the medial aspect of the tibia at the fracture level, and adjacent to the fracture at 1cm distal and 1cm proximal to the fracture. Times of measurement were pre-op, post-op, and at sacrifice. At 28 days the mechanical characteristics of the healed bones were tested in three-point bending by a dorsal deflection of the tibia. The statistical significance of differences in the biomechanical properties was assessed with the non-parametric Wilcoxon test. The protocol was in accordance with the principles of the Guide for the Care and Use of Laboratory Animals and was approved by the local animal care and use committee.

RESULTS

In the control group, blood flow decreased post-op at all measurement locations. One day post-op the reduction in blood flow was largest particularly at the distal location (-71%; fig. 1). From day 1 until day 7 blood flow steadily increased. In the control group the fracture site remained hypovascularized until day 7, while proximally and distally the baseline levels of blood supply were restored by day 3. Blood flow changes at the fracture site differed markedly from the changes observed adjacent to the fracture. At the fracture site, the changes in blood flow in the HES group were similar to the changes in the control group. In the SVR group the reduction in blood flow was less pronounced. Adjacent to the fracture in contrast, the SVR group demonstrated a delay in blood flow recovery (fig. 1). While in the control and HES animals blood flow returned to baseline levels by day 3, the SVR animals required 14 days for the blood flow values to return to normal (fig.1). Adjacent to the fracture blood flow was massively reduced in the control and SVR group, while blood flow in the HES group was only slightly reduced after the fracture event.

The mean bending stiffness in the HES group was four times higher (fig. 2) than in the SVR and the control group (p<0.1). Also the failure load was markedly increased in the HES with three times higher values compared to the control group (p<0.1).

DISCUSSION

In our study fracture healing was not deteriorated by a transient hemorrhagic shock situation. Furthermore, the recovery of blood supply after fracture appeared not to be delayed by a shock situation but rather was improved by employing an adequate resuscitation protocol. The Laser Doppler results showed that the recovery of blood flow was faster distally and proximally of the fracture site than at the fracture site itself. Together with the biomechanical data this would suggest that the early recovery of blood supply at some distance from the fracture may initiate a positive healing response resulting in improved mechanical stability at a later healing stage. The improved blood supply at the fracture site after SVR treatment might be related to an enhanced micro-circulation resulting from decreased peripheral vascular resistance and improved rheologic conditions. Also the hypoxia induced by the shock situation might have improved the neo angiogenesis by an increase in VEGF expression.(2) The different healing responses for SVR and HES are not fully understood. The faster fluid resuscitation in the SVR group may have resulted in a prolonged depression of the immune response.(3) Our study is limited in that the control group did not receive a shock situation and we can only compare normal healing to healing after shock with blood volume resuscitation. However, without resuscitation the survival rate after 20 min of hemorrhagic shock was unacceptably low. The findings of our study indicate that a transient hemorrhagic shock situation followed by isovolumetric blood volume resuscitation results in improved fracture healing. The positive healing response might be associated with improved revascularization of the soft callus adjacent to the fracture site.

REFERENCES

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