Acta Orthop Scand 55, 576–578, 1984

Tourniquet effects on muscle oxygen tension in dog limbs

Experiments with cooling and breathing intervals

The effects of repeated tourniquet applications with breathing periods on muscle pO_2 was studied in adult dogs. A tourniquet was applied to one hind limb. The tourniquet was repeatedly inflated for 1 h; four ischemic periods were separated by 20-min recirculation intervals. In other series the limb was cooled prior to tourniquet application, or the animal was treated with the proteinase inhibitor Trasylol. Following tourniquet deflation, the pO_2 value in the gastrocnemius muscle initially increased, reaching a peak within 5 min. This initial increase became less apparent with repeated periods of ischemia as well as with prolongation of the ischemic period. The results indicate that cooling prior to tourniquet application represents a better technic than the use of breathing periods or Trasylol.

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Inflatable tourniquets are widely used to provide a bloodless field for orthopedic surgery. Most studies have addressed the local effects of tourniquet ischemia (Paletta et al. 1960, Haljamäe & Enger 1975), while some reports have described the systemic effects of tourniquet deflation (Nakahara & Sakahashi 1967, Klenerman et al. 1980). Reviewing the studies on tourniquet ischemia, it seems that two problems still remain: (1) the critical time limit for application of the tourniquet, and (2) the need for a breathing period including re-circulation of the limb during prolonged application of the tourniquet. The latter issue has not been studied since Bruner (1951) suggested a breathing period to prevent tissue damage.

The present study was designed to evaluate the effects of such a breathing period on ischemic muscle.

Material and methods

Eighteen dogs, weighing 10–15 kg, were used. Under pentobarbital sodium (Nembutal®) anesthesia, the tourniquet was applied to one hind limb (Nakahara 1971), and left inflated for 1–4 h. The animals were divided into the following groups:

Group I. The animals were subjected to 1, 2 or 4 h of tourniquet ischemia without adjuvant therapy.

Group II. The animals were subjected to four 1-h periods of tourniquet ischemia, with a 20-min breathing interval between each ischemia period.

Group III. The hind limb was cooled prior to the application of the tourniquet. Cooling was performed by soaking in ice-cold water up to the proximal end of the thigh for 10 min. Immediately after cooling, the tourniquet was applied for 4 h.

Group IV. A single dose of Trasylol (50,000 KIE/10 kg) was given intravenously 10 min prior to the application of the tourniquet for 4 h.

Muscle pO_2 was measured by means of a Unique Medical equipment (POG-201) with a needle-type platinum electrode (JOE-100), Tokyo, Japan. The electrode was inserted into the gastrocnemius muscle and the pO_2 value was continuously recorded. The values given represent the mean ± standard deviation of three to five experiments.

Results

The pre-ischemic pO_2 value of the gastrocnemius muscle was 32 ± 11 mm Hg. After tourniquet application, the pO_2 value of the gastrocnemius muscle rapidly decreased and reached anoxic levels within 15 min. Following release of the tourniquet in Group I, an initial increase in pO_2 values was followed by a gradual decrease; the peak occurred within 5 min after tourniquet release (Figure 1). The highest pO_2 values obtained after 1, 2 and 4-h is-

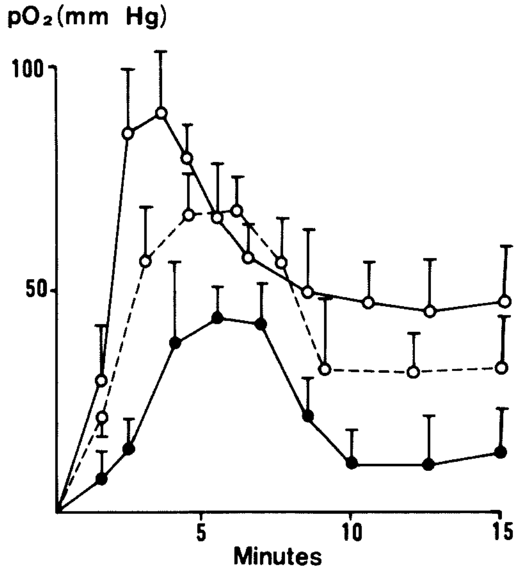

Figure 1. Changes in pO_2 value of the gastrocnemius muscle following tourniquet deflation. The dogs were subjected to 1, 2 and 4 h of tourniquet ischemia. The differences were significant between the highest values obtained after 1-h and 2-h ischemia ($p < 0.05$) and 2-h and 4-h ischemia ($p < 0.01$). ○——○ tourniquet applied for 1 h. ○----○ 2 h, ●——● 4 h.

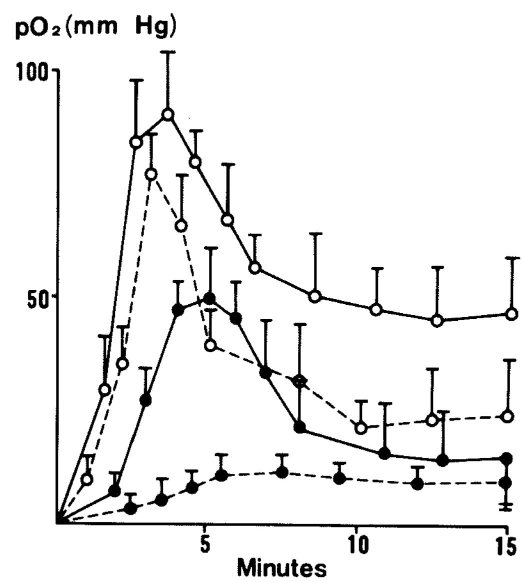

Figure 2. Changes in pO_2 value of the gastrocnemius muscle following tourniquet deflation. The 1-h tourniquet was applied 4 times to each animal, giving a 20-min breathing interval between each inflation. Significance of differences between the highest values obtained after the first and second ischemia periods: $p < 0.1$, after the second and third periods: $p < 0.01$, after the third and the fourth periods: $p < 0.01$. ○——○ the first tourniquet application, ○----○ the second tourniquet application, ●——● the third tourniquet application, ●----● the fourth tourniquet application.

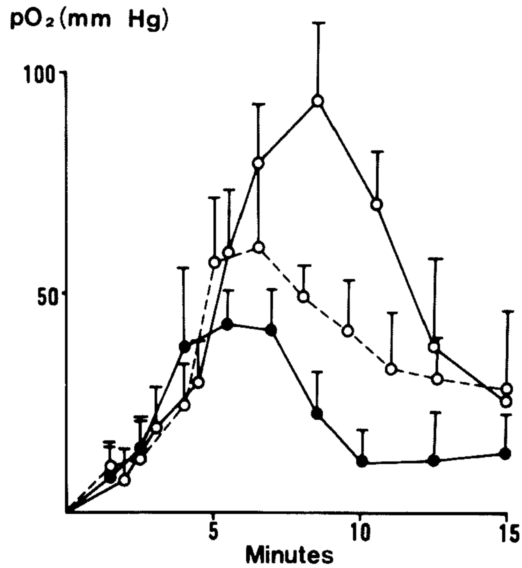

Figure 3. Changes in pO_2 value of the gastrocnemius muscle immediately after 4-h tourniquet application. The dogs were pretreated with local hypothermia or Trasylol. Significance of differences between the highest value obtained from the hypothermia animals and the Group I controls: $p < 0.001$, between the highest value obtained from Trasylol animals and controls: $p < 0.01$. ○——○ 4-h tourniquet application after pretreatment with local hypothermia, ○----○ 4-h tourniquet application after pretreatment with Trasylol, ●——● 4-h tourniquet application only.

chemia were 90 ± 13, 67 ± 9 and 43 ± 8 mm Hg, respectively. The pO_2 values at 10–15 min after tourniquet deflation remained almost steady, the values obtained from the 1-h ischemia, however, remaining higher than the preischemic level ($p < 0.05$). In contrast, the values obtained after the 4-h ischemia remained lower than the preischemic level ($p < 0.02$).

In Group II, in which there was a breathing period at each interval of tourniquet deflation, the initial rise of the pO_2 value became less apparent with repeated ischemia. After the fourth ischemic period no initial rise appeared (Figure 2).

The results in Group III, treated with local hypothermia, and Group IV, treated with Trasylol (Figure 3) were compared with the results obtained after 4-h tourniquet inflation (Figure 1). Although no significant difference was observed on the initial rising gradient, the highest pO_2 values obtained in Groups III and IV were 93 ± 17 and 61 ± 18 mm Hg, respectively.

Discussion

Bruner (1951) discussed the use of a breathing period to extend tourniquet ischemia during prolonged surgical procedures. He suggested that 1 h of tourniquet ischemia should be followed by a 10-min period of re-circulation if the tourniquet had to be re-applied to complete the surgery. Wilgis (1971) suggested that the tourniquet should not be reapplied until the pH, pO_2 and pCO_2 in the blood have returned to normal, i.e. 15–20 min after an ischemic period of 2 h. Haljamäe & Enger (1975) demonstrated that the phosphagen content and clearance of lactate in the ischemic muscle approach control levels by 5 min after tourniquet deflation following 60–90 min of tourniquet ischemia. Klenerman et al. (1980) observed that the acid-base balance returned to normal within 40 min after 2-h ischemia. These discrepancies may be due to differences in materials and methods for assessment.

Measurement of muscle pO_2 with a needle electrode has the advantage that the muscle microcirculation is continuously reflected throughout the experimental period without inducing severe trauma to the muscle. The pO_2 value indicating the peak of the initial rise appearing after tourniquet deflation was higher in Group I without a breathing period than in Group II with a breathing period. This finding may be due to a disturbance in intramuscular microcirculation secondary to edema, quickly developing in the ischemic limb after tourniquet deflation. Furthermore, bradykinin generated by the kinin-kininogen system which is activated by limb ischemia may contribute to the development of edema (Nakahara 1971) as well as increased plasma fibrinolytic activity. The edema developed may exert its effect at the level of the microcirculation, resulting in arteriovenous shunting. Thus, it may not be possible to achieve an adequate oxygen supply to the ischemic muscle tissue by giving a breathing period.

Heparin (Paletta et al. 1960), corticosteroids (Rahmer et al. 1977), Trasylol (Rahmer et al. 1977) and local hypothermia (Paletta et al. 1960) have been used experimentally to minimize the tissue damage induced by tourniquet ischemia. Rahmer et al. (1977) demonstrated that a close correlation exists between the pO_2 value on the muscle surface and the survival time after tourniquet ischemia. The beneficial effects of Trasylol and local hypothermia on muscle pO_2 may be based on an inhibitory action with respect to the edema appearing after tourniquet deflation. Our results indicate that local hypothermia is more effective with respect to restoration of intramuscular microcirculation after prolonged tourniquet ischemia.

Acknowledgement

I am grateful to Miss H. Maekawa for skilled technical assistance.

References

Bruner, J. M. (1951) Safety factors in the use of the pneumatic tourniquet for hemostasis in surgery of the hand. *J. Bone Joint Surg.* **33**-A, 221–224.

Haljamäe, H. & Enger, E. (1975) Human skeletal muscle energy metabolism during and after complete tourniquet ischemia. *Ann. Surg.* **182**, 9–14.

Klenerman, L., Biswas, M., Hulands, G. H. & Rhodes, A. M. (1980) Systemic and local effects of the application of a tourniquet. *J. Bone Joint Surg.* **62**-B, 385–388.

Nakahara, M. & Sakahashi, H. (1967) Effect of application of a tourniquet on bleeding factors in dogs. *J. Bone Joint Surg.* **49**-A, 1345–1351.

Nakahara, M. (1971) The effect of a tourniquet on the kinin-kininogen system in blood and muscle. *Thromb. Diath. Haemorrh.* **26**, 264–274.

Paletta, F. X., Willman, V. & Ship, A. G. (1960) Prolonged tourniquet ischemia of extremities. An experimental study on dogs. *J. Bone Joint Surg.* **42**-A, 945–950.

Rahmer, H., Durst, J. & Schubert, G. E. (1977) Correlation between local oxygen tension in muscle tissue and survival time in tourniquet shock. *Circ. Shock* **4**, 35–40.

Wilgis, E. F. S. (1971) Observations on the effects of tourniquet ischemia. *J. Bone Joint Surg.* **53**-A, 1343–1346.