Acta orthop. scand. *49*, 415–419, 1978

EFFECT OF PNEUMATIC TOURNIQUET ON MUSCLE OXYGEN TENSION

SEPPO SANTAVIRTA, KRISTER HÖCKERSTEDT & JUHA NIINIKOSKI

Division of Orthopaedic Surgery and Traumatology, Surgical Hospital, and the Fourth Department of Surgery, University Central Hospital, Helsinki, and the Department of Surgery, University of Turku, Turku, Finland

Recent investigations suggest that circulation in a limb can be reduced with a tourniquet to less than 1 per cent of the control limb, or even completely occluded. The development of tissue oxygen tonometry with implanted silastic tubes has provided new possibilities for assessing muscle tissue oxygen tension. In the present work, this method was employed to register the effect of tourniquet blockade on the lower limb muscle PO_2 in rabbits. The duration of the tourniquet blockade was 60, 120 and 180 minutes. The baseline muscle PO_2 in the tibialis anterior muscle was 22.6 ± 0.6 mmHg. During the tourniquet blockade the oxygen tension dropped to minimal values between 9.2 ± 0.5 and 10.7 ± 0.6 mmHg in these experimental groups, but the tissue microclimate never reached fully anoxic conditions. The rapid response of muscle PO_2 to oxygen breathing after release of the blockade suggests that limb microcirculation tolerates tourniquet occlusion well.

Key words: pneumatic tourniquet; tissue PO_2; silastic tonometer

Accepted 31.iii.78

The clinical advantages of a pneumatic tourniquet are well known, since surgery in a bloodless field has been practised for over a century (Esmarch 1873). However, maintaining tourniquet blockade involves disadvantages, the greatest of which is probably tissue ischaemia.

Recent investigations suggest that circulation in a limb can be reduced with a tourniquet to less than 1 per cent of the control limb (Klenerman & Crawley 1977). The resistance of the microcirculation of striated muscle against ischaemia is largely unknown. In recent studies the role of tissue oxygenation in operative procedures has been emphasized (Kivisaari & Niinikoski 1975, Niinikoski 1977).

The development of tissue oxygen tonometry with implanted silastic tubes (Niinikoski & Hunt 1972) has provided new possibilities for investigating muscle tissue oxygen tension. In the present work, this method was employed to register the effect of tourniquet blockade on the lower limb muscle PO_2 in rabbits.

MATERIAL AND METHODS

Seventeen rabbits of both sexes, weight 3.0–3.9 kg, were used in this study. Anaesthesia was induced with intravenous sodium pentobarbitone and maintained by continuous ether inhalation. The skin of the left hind leg was incised, and a loop of silastic tube, length 16 cm, outside diameter 1.40 mm and inside diameter 0.9 mm (Holter® Atrial Catheter J, A 190, Extracorporeal

Medical Specialties Inc., Millis, Mass., USA) was implanted in the tibialis anterior muscle (Figure 1). The implantation was made through a wide-bore needle. The tube ends were left outside the skin after closure and fixed with a silk ligature. A length of 14 to 15 cm remained inside the muscle tissue. Three days later the rabbit was again anaesthetized and muscle oxygen tension was determined according to Niinikoski & Hunt (1972). The silastic tonometer was perfused continuously with hypoxic saline, PO_2 3 to 8 mmHg, with a slow injection pump (Model 1100, Harvard Apparatus Co. Inc., Millis, Mass., USA), and tissue PO_2 was measured from the efflux in the Radiometer gas monitor coupled with a Servogor[R] chart recorder (Goerz Electro GmbH, Vienna, Austria). Oxygen impermeable nylon catheters were used as connector tubes in the perfusion system. The response of different durations of tourniquet blockade was measured. Five rabbits had 60-minute tourniquet ischaemia and in five animals ischaemia lasted for 120 or 180 minutes, respectively. The tourniquet ischaemia was maintained by means of a 6 cm broad, Riva-Rocci-type cuff around the upper part of the leg. The cuff was inflated to 300 mmHg. In each animal the response of the muscle oxygen tension to the release of tourniquet and to breathing of pure oxygen was also registered. In two cases the tourniquet blockade lasted 30 minutes and breathing of pure oxygen was continued throughout the whole experiment.

Figure 1. The site of the silastic tube implantation in the tibialis anterior muscle in a rabbit. X-ray shows the contrast medium filled tube.

RESULTS

The baseline PO_2 before the application of the pneumatic tourniquet ranged between 18 and 26 mmHg (mean and SEM 22.6 $\pm$ 0.6 mmHg). Breathing of pure oxygen for a period of 15 minutes increased the level of intramuscular PO_2 to 90–130 mmHg.

During 60 minutes of tourniquet ischaemia the intramuscular PO_2 declined from the baseline value of 22.2 $\pm$ 1.2 mmHg to a minimal value of 9.3 $\pm$ 0.6 mmHg within 20–24 minutes (Figure 2a). After release of the tourniquet the PO_2 reached a stable value of 17.8 $\pm$ 0.8 mmHg in 5 to 10 minutes and then remained unchanged during the following 30 minutes. When the PO_2 had been stabilized, the rabbits were exposed to pure oxygen through a head tent. This resulted in an intramuscular PO_2 of 85–130 mmHg within 15 to 20 minutes.

During 120 minutes of tourniquet ischaemia the PO_2 declined from the baseline value of 23.7 $\pm$ 1.1 mmHg to a minimal value of 10.7 $\pm$ 0.6 mmHg within 22 to 28 minutes (Figure 2b). In 5 to 10 minutes after release of the tourniquet, the PO_2 reached a stable level

of 19.5 ± 0.8 mmHg. The intramuscular PO_2 responded in all cases to oxygen breathing with an increase to 80–120 mmHg.

During 180 minutes of tourniquet ischaemia the PO_2 declined from the baseline value of 21.7 ± 1.1 mmHg to a minimal value of 9.2 ± 0.5 mmHg within 19–26 minutes (Figure 2c). After releasing the tourniquet, the PO_2 reached a stable level of 17.0 ± 0.5 mmHg in 10–17 minutes. The response to pure oxygen breathing was an increase of the intramuscular PO_2 to 90–115 mmHg.

When pure oxygen breathing was continued throughout the experiment, a decline of the PO_2 from 120 mmHg to 11 mmHg was registered (Figure 3).

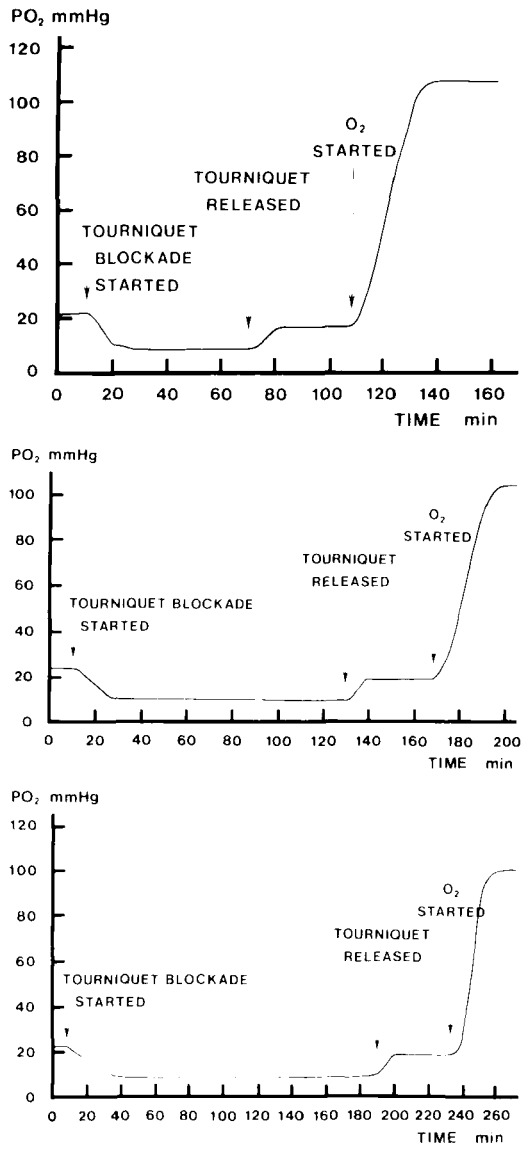

Figure 2. (a) Effect of 60-minute tourniquet blockade on muscle PO_2. (b) Effect of 120-minute tourniquet blockade on muscle PO_2. (c) Effect of 180-minute blockade on muscle PO_2.

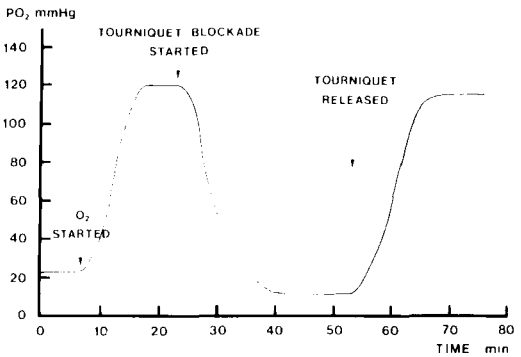

Figure 3. Effect of pure oxygen breathing continued throughout the experiment. A decline of the PO_2 from 120 mmHg to 11 mmHg was registered.

DISCUSSION

The silastic tonometer method of measuring tissue oxygen tension is already well established and has showed its usefulness in several studies. Niinikoski et al. (1972) showed that the silastic tube induces a minimal foreign body reaction.

Kivisaari & Niinikoski (1973) concluded that one of the main problems involved in measuring tissue gases by means of microelectrodes is the wide topographical variation of the PO_2 readings that normally occurs (Silver 1969). The advantage of the silastic tonometer is that it measures the average extracellular tissue PO_2 (Niinikoski & Hunt 1972).

In earlier investigations the silastic tonometer has been used extensively in several tissues, such as human subcutaneous tissue (Niinikoski et al. 1972, Kivisaari & Niinikoski 1973, Heppenstall et al. 1974), human muscle (Cooke et al. 1974), intestinal

wall and peritoneal cavity in animals (Inberg et al. 1974, Klossner et al. 1974), canine lung (Havia & Niinikoski 1976) and canine heart (Havia & Niinikoski 1977).

The reported mean baseline PO_2 values have varied in most tissues between 20 and 30 mmHg. In rabbit subcutaneous tissue PO_2 varied between 20 and 25 mmHg (Niinikoski & Hunt 1972). Canine myocardium PO_2 ranged from as low as 8 to 40 mmHg with a mean of 22 mmHg.

The baseline muscle PO_2 ranged in our study from 18 to 26 mmHg. This is compatible with the tissue oxygen tensions reported in other studies.

In the present study, the application of tourniquet always produced a decline in the intramuscular oxygen tension. The minimal value of 9–11 mmHg was achieved in 19–26 minutes and then remained constant during the rest of the tourniquet time, but never reached zero. In accordance with the present findings, Niinikoski et al. (1972) found it puzzling that a 20-minute occlusion of limb circulation did not result in a PO_2 of zero in human subcutaneous tissue. In the investigation of Kivisaari & Niinikoski (1975) the intraosseous PO_2 fell abruptly after circulatory arrest so that most of the decrease occurred within 2 minutes, but also in this case the PO_2 never reached zero. Furthermore, the release of circulation resulted momentarily in a PO_2 slightly above the normal level, probably due to reactive hyperaemia (Niinikoski et al. 1972, Kivisaari & Niinikoski 1975). In the present study, the muscle PO_2 remained slightly under the normal level after releasing the blockade. However, after a few minutes of pure oxygen breathing, the PO_2 increased sharply. This indicates that the microcirculation even after 3 hours of tourniquet blockade was functioning well.

Continuous oxygen breathing during the tourniquet experiment had no influence on the decrease of the PO_2 and the minimal value was compatible with the one achieved with room air breathing. This has been interpreted as total occlusion of the circulation caused by the tourniquet. The decline of PO_2 and recovery after tourniquet release seemed to be independent of tourniquet time.

It can be concluded that inducing a total blockade of local circulation in an extremity produces a profound fall of the muscle PO_2, but the tissue microclimate never reaches fully anoxic conditions. The rapid response of muscle PO_2 to oxygen breathing after release of the blockade suggests that tissue oxygenation is rapidly restored after tourniquet release.

ACKNOWLEDGEMENTS

This work was supported by the Emil Aaltonen Foundation and Paulo Foundation. The authors wish to thank Mrs. Päivi Pennanen and Mrs. Irmeli Lautenschlager for skilful technical assistance.

REFERENCES

Cooke, P., Heppenstall, R., Littooy, F., Hunt, T. K. & Wylie, E. (1974) The tissue oxygen tension as an index of collateral blood flow during acute arterial blood occlusion. *S. Afr. J. Surg.* **12**, 91–99.

Esmarch, J. (1873) Ueber kuenstliche Blutleere bei Operationen. Sammlung klinischer Vorträge im Verbindung mit deutschen Klinikern. *Chirurgie* **19**, 373–383.

Havia, T. & Niinikoski, J. (1977) Intramyocardial gas tensions in the canine heart. *Scand. J. thorac. cardiovasc. Surg.* **11**, 89–96.

Havia, T. & Niinikoski, J. (1976) Parenchymal gas tensions in canine lung. *Scand. J. thorac. cardiovasc. Surg.* **10**, 243–246.

Heppenstall, R., Littooy, F., Fuchs, R., Sheldon, G. & Hunt, T. K. (1974) Gas tensions in healing tissues in traumatized patients. *Surgery* **75**, 874–880.

Inberg, M., Havia, T., Arola, M. & Niinikoski, J. (1974) Effect of oxygen breathing on jejunal tissue gas tensions during superior mesenteric arterial occlusion. *Scand. J. Gastroent.* **9**, 337–342.

Kivisaari, J. & Niinikoski, J. (1973) Use of silastic tube and capillary sampling technic in the measurement of tissue PO_2 and PCO_2. *Amer. J. Surg.* **125**, 623–627.

Kivisaari, J. & Niinikoski, J. (1975) Tissue oxygen and carbon dioxide tensions in healing rabbit tibias. *Acta orthop. scand.* **46**, 269–279.

Klenerman, L. & Crawley, J. (1977) Limb blood flow in the presence of a tourniquet. *Acta orthop. scand.* **48**, 291–295.

Klossner, J., Kivisaari, J. & Niinikoski, J. (1974) Oxygen and carbon dioxide tensions in the abdominal cavity and colonic wall of the rabbit. *Amer. J. Surg.* **127**, 711–715.

Niinikoski, J. & Hunt, T. K. (1972) Measurement of wound oxygen with implanted silastic tubes. *Surgery* **71**, 22–26.

Niinikoski, J., Heughan, C. & Hunt, T. K. (1972) Oxygen tensions in human wounds. *J. Surg. Res.* **12**, 77–82.

Niinikoski, J. (1977) Oxygen and wound healing. *J. Clin. Plast. Surg.* **4**, 361–374.

Silver, I. (1969) The measurement of oxygen tension in healing tissue. *Progr. Resp. Res.* **3**, 124–135.

Correspondence to: Seppo Santavirta, M.D., Division of Orthopaedic Surgery and Traumatology, Surgical Hospital, University Central Hospital, Kasarmik. 11–13, Helsinki 13, Finland.