Guest editorial

Bloodless field and tourniquet compression

The bloodless field is widely used in extremity surgery. However, serious complications have been reported, and frequent observations of postoperative paresthesiae, numbness, and muscle weakness have caused many surgeons to ask themselves whether the use of the bloodless field is sufficiently safe to be justified.

The tolerance to ischemia may vary from minutes (central nervous cells) to days (e.g., skin). Tissues already damaged by injury have notably less tolerance to circulatory arrest. In extremities subjected to tourniquet-induced ischemia, the picture is further complicated by the combined ischemic and mechanical trauma that is induced beneath an inflated tourniquet. And the postischemic swelling of tissues is an additional complication.

Although tourniquet-induced ischemia is associated with potential risks, the induction and maintenance of such ischemia should not be regarded as more dangerous than, for instance, an axillary block and the potential risks of nerve injury associated with such a procedure. On the contrary, if the bloodless field is used *correctly*, it has the same potential of facilitating and enabling surgical procedures as an adequate anesthesia. In extremity surgery, bloodlessness makes it possible to perform delicate procedures expeditiously and with minimal risk of damaging adjacent structures. Anyone with experience from extirpating a foreign body from a fingertip, decompressing a median nerve, or performing a knee arthroplasty should concur with such a statement.

What, then, is the correct use of the bloodless field? To answer this question, the possible deleterious effects of ischemia distal to the tourniquet and the compression beneath the tourniquet must be considered.

In the literature, the critical ischemic period has varied depending on the technique and criteria used for the definition and assessment of the ischemia-induced injury. For instance, there seems to be a general consensus that muscle tissue tolerates about 4 hours of ischemia. This statement is based on histologic observations of muscle-fiber degeneration following ischemia (Harman 1947). On the other hand, swelling of mitochondria—the first critical sign of muscle injury—occurs already after 30 minutes (Dahlbäck and Reis 1966). Dramatic, though reversible, metabolic changes occur in ischemic muscle within minutes (see Haljamäe's review of 1991).

With respect to immediate *functional* effects, nerve fibers are more vulnerable than muscle; conduction ceases within 30–60 minutes of ischemia, i.e., during an ischemic period when muscle tissue still contracts upon direct stimulation (Lundborg 1970). On the other hand, in a more extended perspective, nerves are *less* vulnerable to ischemia than muscle: even after 6 hours of ischemia, nerve conduction may recover within minutes.

Data on tissue tolerance to ischemia per se is, however, of limited interest as regards the bloodless field. In tourniquet-maintained ischemia, nerve and muscle lesions are always worse at *the level of the tourniquet* because mechanical trauma is added to the ischemia.

This is the basis for our current concepts of the etiology of tourniquet palsy. This type of neuromuscular disorder is usually not a result of too prolonged ischemia, but a result of local *mechanical* injury caused by compression of the tourniquet. In a review of published reports on neuromuscular complications following a bloodless field, it was found that 14 out of 16 complications were due to neuromuscular injury at the tourniquet level (Lundborg 1988). In 12 of these cases, the cause was simple: too high pressure in the tourniquet due to errors in manometer calibration. In some cases the ischemic period was as short as 30 minutes.

The message is simple and clear: the majority of the complications can be avoided if more attention is paid to the tourniquets, and especially to pressure magnitudes. Recent data indicate that also the width and design of the tourniquet are of importance in this context. The tissue deformation caused by an inflated tourniquet is always maximal at the edges of the tourniquet owing to shearing forces displacing compressed tissue to noncompressed areas. Beneath the cuff the pressure distribution is greatly influenced by the shape of the tourniquet, with wide tourniquets inducing a more effective and physiologic pressure distribution than narrow tourniquets. In animal experiments, tourniquets specially designed to fit the conical shape of an extremity contributed to the effectiveness of pressure distribution (Pedowitz et al. 1990).

The facts discussed here are emphasized in Dr. Pedowitz's supplement to the October 1991 issue of *Acta Orthop Scand.* In his study, attention was focused on the tourniquet, with particular emphasis on muscle injury induced by tourniquet compression and as assessed by isotope techniques. The data presented are on many points of considerable relevance for the clinical use of tourniquets.

Thus, serious complications from the use of tourniquets can be prevented by following some simple rules.

1. The equipment inducing the tourniquet pressure should be regularly checked and calibrated to ensure a correct indication of tourniquet pressure.
2. The pressure in the tourniquet should be maintained as low as possible. Reasonable pressures are respectively 70 mmHg and 100–150 mmHg above systolic pressure for the upper and lower extremities. With optimization of tourniquet design, these pressure levels could probably be further decreased.
3. The application of the tourniquet should be carefully checked, especially as regards the margins of the tourniquet. Adequate padding is of cardinal importance, particularly if the protective muscle mass of the upper arm is reduced.
4. The tourniquet application time should be kept as short as possible, with 1–2 hours serving as the maximal time.

A difficult question to answer is how to apply the bloodless field in extended, several-hour-long surgical procedures. In such cases, it is usually recommended that an initial period of cuff application be followed by 15-minute "breathing periods" for recirculation. However, data are lacking as regards optimal application of such a principle. Repeated shifts between aerobic and anaerobic conditions with dramatic changes in metabolic states may not necessarily be preferable to a prolonged anaerobic environment. Indeed, Pedowitz (1991) demonstrated that, with *high* pressure in the tourniquet, repeated periods of compression interrupted by "breathing periods" induce more severe muscle damage than a single continuous period of cuff compression. On the other hand, with minimal pressure in the cuff, repeated periods of cuff compression interrupted by "breathing periods" induce less muscle injury than a continuous period of cuff compression.

Much research remains to be done, particularly with reference to the use of the bloodless field in extended surgical procedures. Other important topics for future research include possible ways to increase tolerance to ischemia/compression and to reduce tissue damage during or after surgery by means of such extrinsic factors as cooling, hyperbaric oxygen, and treatment with vascular perfusates during/after the bloodless field.

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