Narrow elastic disposable tourniquet (Hemaclear®) vs. traditional wide pneumatic tourniquet for creation or revision of hemodialysis angioaccesses

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ABSTRACT

Purpose: To choose the best arterial tourniquet for angioaccess surgery.

Methods: Preventive hemostasis with an arterial tourniquet prevents bleeding and provides better visualization. The surgeon may currently use a traditional wide nonsterile inflatable pneumatic cuff after exsanguination with an Esmarch bandage or a disposable sterile narrow elastic silicone ring (HemaClear®), available in different sizes according to the patient’s limb circumference and blood pressure.

Results: The latter is easily rolled up the upper limb after surgical draping, to achieve exsanguination and occlusion of the proximal brachial artery, thus providing a wide sterile field that is most useful for upper arm vein superficialization or arteriovenous fistula (AVF) revision. Although rare, neurological complications must be prevented by limiting the compressive force applied to the tissues to occlude the arteries and the veins. Such tissues are almost non-compressible but deformable; thus, they may be elongated and damaged, mostly at both extremities of the tourniquet, especially the nerves. The compressive force (kg) applied to the limb by the cuff is the product of the cuff pressure (mm Hg) imposed and the surface (cm²) of the skin in contact with the cuff. Reduction of the cuff surface results in reduction of the volume of tissue beneath the cuff and therefore in limitation of the compressive force.

Conclusions: From a theoretical point of view and from clinical data, it seems therefore reasonable to recommend the use of a narrower cuff size and, for practical reasons, the silicon ring.

Keywords: Arteriovenous fistula, Preemptive hemostasis, Tourniquet

Introduction

Preventive hemostasis is routinely used by the authors for every angioaccess procedure located at or below the mid upper arm. For arteriovenous fistula (AVF) creation (1), the main benefit of preventive hemostasis in association with microsurgery is improved visualization of anatomical details, allowing for creation of distal AVF in most patients, even in small children. The second benefit is the prevention of possible spasm of the radial artery, related to the surgical dissection and ligation of collaterals that are necessary when instrumental clamping is employed. For angioaccess revision procedures (2), one more benefit of preventive hemostasis is the total absence of blood loss, even during high flow access revision.

The device traditionally used is the pneumatic tourniquet, inflated after limb exsanguination using an Esmarch elastic bandage. Nevertheless, in a study published in 1974 (3) about half the surgeons were still using an Esmarch bandage as a tourniquet. This can produce extremely high tissue pressure, and a disproportionate number of complications may be related to such use.

An elastic, non-pneumatic narrow disposable silicone ring tourniquet (HemaClear®, OHK Medical Devices, Haifa, Israel) was introduced recently to clinical practice to achieve both exsanguination and occlusion of arterial flow.

The aims of this review are to compare the clinical use of the classical wide pneumatic tourniquet with the use of the narrow silicone elastic ring tourniquet, and to re-evaluate the risks and the theoretical basis of preventive hemostasis for surgical angioaccess procedures.

Tourniquets are used at both the upper and lower limbs. However, in the present paper we mainly describe and discuss their use in the creation or revision of angioaccesses in the upper limb.
Clinical use of pneumatic tourniquets

Preventive hemostasis is implemented after completion of echo-guided regional anesthesia and intravenous administration of prophylactic antibiotics, before sterile surgical draping. The size of the tourniquet is chosen according to the caliber of the proximal part of the upper limb, traditionally using a wider tourniquet for obese patients. European and US guidelines recommend using a cuff with a width at least 0.3 times the limb circumference (4, 5). A wrinkle-less padding beneath the tourniquet is mandatory. Exsanguination must be as complete as possible using the Esmarch elastic bandage. For small children and for older patients with fragile skin, a narrow non-elastic bandage is more convenient for exsanguination. The tourniquet is then inflated to 50 mm Hg above the arterial systolic pressure. It is recommended not to exceed one hour before deflation. This is long enough for the creation of the fistula. After deflation of the tourniquet, the patency of the anastomosis should be checked by visible dilatation of the vein, thrill palpation or evidence of a permanent signal with systolic reinforcement on sterile Doppler examination, the latter two being positive signs of a well-functioning AVF. Finally, the hemostasis is completed and the incision closed.

In the case of incomplete exsanguination, any persistent bleeding or minimal leaking of plasma while suturing the anastomosis may be responsible for blood coagulation or deposits of fibrin, resulting in primary thrombosis. In such conditions, atraumatic clamps should be placed on both sides of the artery opening to stop any leakage.

The duration of tourniquet inflation is still a matter of debate. One hour is generally considered to be a safe limit, but on the basis of current data some authors consider two hours to be a widely accepted limit. One hour is in fact a sufficient amount of time for the vast majority of angioaccess creations but this may be too short for complex AVF revision.

The traditional pneumatic tourniquet is usually too wide to be used for access surgery above the lower third of the upper arm, i.e., the second stage of superficialization of the upper arm basilic or cephalic vein and brachio-axillary graft. Some other contraindications have been reported, most being only relative contraindications. In our experience, preventive hemostasis for AVF creation in patients with sickle cell disease for frequent exchange transfusions has been uneventful. In cases of highly calcified arteries, the tourniquet may be only partly effective. Finally, the use of a tourniquet is questionable for revision of angioaccesses associated with distal ischemia.

In cases of massive hemorrhage related to skin necrosis at the puncture site, immediate local finger pressure will easily stop the bleeding. A compression bandage (reinforced, if necessary, with a pneumatic arterial blood pressure cuff or better still an orthopedic surgery tourniquet) can then be applied to the bleeding site and the patient should be urgently transferred to the operating theatre. Surgical revision can then be performed, ideally using preventive hemostasis, but some upper arm lesions may be situated too high for proximal application of a pneumatic tourniquet.

One limitation of the traditional pneumatic tourniquet is the risk of infection. In the absence of ethylene oxide sterilization, significant contamination with bacteria commonly involved in surgical site infections may be found on most tourniquets and Esmarch bandages used in orthopedic theaters (6).

Clinical use of elastic silicone ring tourniquets

The silicone ring device is made of a narrow, sterile, disposable, elastic ring, and pull straps wrapped in a stockinet sleeve. The size is determined after measuring the limb circumference of the patient at the required occlusion site. The full range of available sizes covers infants to obese adults for the upper extremity and for different blood pressures. The HemaClear®/40-yellow upper arm model (Fig. 1) is suitable for most adult patients with upper limb circumferences ranging from 24 to 40 cm and systolic arterial pressure of <190 mm Hg. After surgical sterile draping, the ring is easily and rapidly rolled up the upper limb by pulling the straps to produce exsanguination (>95% of the limb blood volume), up to the proximal part of the upper arm to occlude the brachial artery blood flow.

The main practical advantages of this device are usability, sterility and narrowness of the ring (<2 cm in width) allowing a large sterile field, and this is necessary for upper arm vein superficialization or AVF revision.

For a primary forearm or upper arm AVF, a protective card is placed underneath the silicone ring after completion of the anastomosis. The ring is then cut with a scalpel and removed, before final hemostasis and skin suture (Fig. 2). For superficialization of the cephalic vein by lipectomy (7), it is recommended to grasp and elevate a portion of the ring in front of the brachial artery with two forceps at the end of the procedure. This will momentarily release the compression of the artery in order to check the function of the angioaccess, before cutting the ring. The same maneuver is used after superficialization of
Nerve complications due to tourniquet application

Incidence

Pneumatic tourniquet

The incidence of neurological complication in Australia in the 1970s following use of a tourniquet was approximately one to 5000 applications on the upper limb. Thirty-three years later, in 2006, one severe neurological complication was reported in Norway for approximately every 6000 tourniquet applications to the upper limb. During that interval, in spite of modifications to the pneumatic tourniquet with lower and more controlled pressures, there has been no reduction in the total incidence of neurological complications following tourniquet application (3).

Elastic ring

Gavriely in 2010 (9) reported that the prevalence of nerve damage available to OHKMedical Devices following the use of its S-MART/ HemaClear® was 2/100,000. Now, with more than 800,000 applications worldwide, not one case of long-term tourniquet nerve injury has been reported (Gavriely, personal communication). Nerve complications were reported to have occurred only when the device was used beyond the recommended 120-minute time limit. In 2012 Reyenders (unpublished data) reported an overall 0.5% complication rate after 4870 HemaClear® applications (20% upper limb). These were: lung embolism 2 (lower limb), thigh pain 12, slight paresis 5, and imperfect visualization 12 (9 upper limb). In 2013 Drosos et al (10) reported no related complications in 536 orthopedic operations, including 219 upper limbs, but the tourniquet failed in 14 patients (2.6%), possibly related to unexpectedly elevated blood pressure or incorrect selection of HemaClear® type. In cases of tourniquet failure with persisting bleeding, it is urgent to remove the ring and restore circulation (11).

Etiology: ischemia or compression or both?

It is generally agreed that the incidence and severity of nerve complications is related to both excessive and prolonged pressure applied to nerves beneath the cuff, rather than to ischemia.

Ochoa et al (12) used a tourniquet to produce long-standing conduction blocking in the peripheral nerves of baboons. They found a characteristic lesion (lateral displacement of Ranvier’s nodes with rupture of the stretched paranodal myelin) preceding paranodal demyelination. The anatomical features and distribution of this lesion (maximal at both edges of the cuff) suggest that the damage to the nerve fibers is a direct result of the pressure applied (force), and not a consequence of secondary ischemia. The consequences for the nerves are different according to the force of the compression: 1) Mild compression of the nerve fibers produces a physiological block which is reversed as soon as the compression pressure is released. 2) Severe compression may actually crush the fibers and leads to Wallerian degeneration; the response of the nerve distal to the lesion is then lost and possible recovery may take months. 3) Intermediate severe compression may result in a local lesion (modification of Ranvier’s nodes) with preservation of distal conduction; this may take several weeks to recover.

Graham et al (13) experimented with pressure transducers placed adjacent to the radial, median and ulnar nerves in the upper extremities of six cadavers of average dimensions. His conclusions were: 1) the pressures applied to a normally sized arm by an externally applied tourniquet cuff are transmitted to underlying peripheral nerves with no significant attenuation in the intervening soft tissues (confirming and documenting the hypothesis of incompressible tissue), 2) the highest tissue pressures are manifested under the midpoint of the cuff and the lowest pressures are under the cuff edges, and 3) at higher levels of inflation the pressure gradient between areas under the edges and midpoint of the cuff may result in the creation of deleterious transverse shear forces applied to the nerves.

Discussion: wide or narrow tourniquets?

Mittal et al (14) noted that wider cuffs have been reported to cause reduced risk of tourniquet-induced injury to the underlying soft tissues than narrower cuffs due to the fact that lower occlusion pressures are caused by the former. To
address and investigate this question, conduction in the median nerve was measured proximal to the tourniquet as well as distal to the tourniquet, by Graham et al (15). Elastic cuffs 14 cm and 7 cm wide were applied to the upper extremities of 20 healthy, normotensive volunteers. Systolic blood pressure was first measured and the cuff was then inflated to 20-30 mm Hg above this and was kept inflated for 15 minutes. Recordings were made prior to the period of tourniquet inflation, and following release of the tourniquet. Nerve conduction velocity was more severely affected by the 14 cm cuff than by the 7 cm cuff. The conclusion was that wider cuffs resulted in more severe changes in the nerve.

The damage caused to the tissues and particularly to nerves beneath the cuff depends on several parameters, i.e., the duration of compression, the mechanical stress imposed on the nerves, and the volume of compressed tissues: for identical cuff pressure, the longer the length of nerve under the cuff, the greater the likelihood of nerve damage.

Moreover, the notion of mechanical stress requires more clarification. For an arm circumference of 35 cm and a cuff width of 14 cm (surface of the cuff-skin contact: 35 × 14 = 490 cm²) inflated at 200 mm Hg (or 266 g/cm²), the total force applied to the arm is 490 × 266 = 130 kg. For the identical inflation pressure (200 mm Hg), a 7 cm wide cuff positioned on the same arm (circumference 35 cm) will result in a total applied force of 7 × 35 × 266 = 65 kg. Using a 1.4 cm thick radial nerve between basal resting conditions, compression for 20 minutes with either a silicon ring or a pneumatic tourniquet placed on the upper non-dominant limb of 14 healthy human volunteers, visualized by 3 Tesla magnetic resonance imaging (MRI), using high-resolution (2.5 mm slice thickness) axial T2-weighted sequences. They could not detect any significant difference in the diameters of median and radial nerves between basal resting conditions, compression by HemaClear® and by the standard pneumatic tourniquet. Their previous hypothesis that a narrow silicone ring causes more pressure to the nerve compared to a wide tourniquet was not proven. Because tissues, and especially muscles, are basically uncompressible but deformable, any force applied to a limb area will produce their deformation and mobilization from that area to both upper and lower parts of the limb. Figure 3 shows MRI images of both left and right upper limbs at the cuff level of a pneumatic tourniquet (A, B) or HemaClear® device (C, D). The images clearly show that the muscular tissue volume was markedly reduced at the cuff level. It can be supposed that the muscle, and hence both vessels and nerves at this level, were stretched during compression. This longitudinal stretch may cause damage to the nervous tissue, as previously demonstrated by Ochoa et al (12).

Finally, to minimize the deleterious effects of cuff pressure for vascular surgery of the limb, three parameters can be modified: the magnitude and the duration of the occluding pressure and the volume of the compressed tissues. The goal of pressure devices (pneumatic tourniquet or silicon ring) is the same, i.e. to transmit pressure to the underlying limb artery that is greater than the systolic arterial blood pressure. Actually, the wider the cuff, the greater the volume of the compressed tissues and the length of stretched nerves. We may therefore expect more severe nerve and tissue damage with wider cuff sizes. Doubling the cuff width will result in doubling the cuff-skin surface and hence the total force applied (kg) to the arm of the patient is proportional to the width of the cuff.

This is in agreement with morphological measurements performed under experimental conditions: Kovar et al (16) assessed the morphological grade of median and radial nerve compression for 20 minutes with either a silicon ring or a pneumatic tourniquet placed on the upper non-dominant limb of 14 healthy human volunteers, visualized by 3 Tesla magnetic resonance imaging (MRI), using high-resolution (2.5 mm slice thickness) axial T2-weighted sequences. They could not detect any significant difference in the diameters of median and radial nerves between basal resting conditions, compression by HemaClear® and by the standard pneumatic tourniquet. Their previous hypothesis that a narrow silicone ring causes more pressure to the nerve compared to a wide tourniquet was not proven. Because tissues, and especially muscles, are basically uncompressible but deformable, any force applied to a limb area will produce their deformation and mobilization from that area to both upper and lower parts of the limb. Figure 3 shows MRI images of both left and right upper limbs at the cuff level of a pneumatic tourniquet (A, B) or HemaClear® device (C, D). The images clearly show that the muscular tissue volume was markedly reduced at the cuff level. It can be supposed that the muscle, and hence both vessels and nerves at this level, were stretched during compression. This longitudinal stretch may cause damage to the nervous tissue, as previously demonstrated by Ochoa et al (12).

**Conclusion**

Preventive hemostasis allows for better vision, limited dissection of vessels and complete absence of blood loss when creating or revising arteriovenous angioaccess shunts. Neurological complications related to tourniquet application are rare but may be dramatic.

Both wide and narrow occluding tourniquets must be applied to the limb artery at a pressure higher than the systolic arterial pressure to result in arterial occlusion and thus cessation of bleeding. However, the total force applied to the
tissues, especially the nerves, and also the volume of compressed soft tissues, are far greater when wide size cuffs are used. Furthermore, a narrow elastic ring has several practical advantages for the surgeon. We therefore recommend the use of narrow silicon rings for angioaccess surgery, especially for arteriovenous fistulas.

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