

Complications of the arterial tourniquet

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Introduction

The arterial tourniquet is commonly used for upper- and lower-limb surgery to optimise operating conditions. The tourniquet reduces bleeding, improves visualisation, and expedites surgical procedures.

However, a number of complications, both localised and systemic, relate to tourniquet use. Although rare, these can be devastating, and may contribute to prolonged hospitalisation, and cause permanent loss of function, or damage to the limb.

In order to minimise possible complications, it is important to understand the physiological effects of tourniquet use, and to follow recommended safety practices pertaining to their use.

Complications of tourniquet use are due to mechanical compression of underlying structures, as well as ischaemia, and reperfusion effects. These result in localised, as well as systemic, complications.

Localised complications

Muscle injury

Muscle injury is due to mechanical compression beneath the cuff, ischaemia beneath and distal to the cuff, and reperfusion injury, following tourniquet release. The injury is greatest beneath the cuff due to the combined effects of all three. Injury increases with greater inflation pressures, and increased duration of ischaemia, but muscles are most susceptible to prolonged ischaemia.

Muscle directly beneath the cuff, subjected to both compression and ischaemia, is most severely affected, and local fibre necrosis is seen after an inflation time of two hours. It takes four hours for this to occur in distal muscle.

During ischaemia, oxygen is rapidly depleted, followed by glycogen stores and other substrates. Creatine phosphate

is depleted within two hours, and adenosine triphosphate, within three hours. There is a build up of ischaemic metabolites: CO₂, K⁺, lactate, H⁺, as well as toxic oxygen radicals, eg. hydrogen peroxide. With reperfusion, further oxygen free radicals are formed, and rapid calcium influx occurs, worsening the injury by causing cellular necrosis. There is also increased microvascular permeability with reperfusion, resulting in swelling and oedema.

Routine tourniquet use results in weakness of the muscle, and delayed postoperative recovery, due to the damage caused.

Post-tourniquet syndrome results in a swollen, stiff, weak limb, thought to be due to ischaemic injury and oedema, following reperfusion. It usually resolves with one to six weeks.

A compartment syndrome may develop with prolonged tourniquet use, although this is rare. This can have catastrophic consequences if not recognised, and decompressed, early. Haggis et al reported on seven cases of compartment syndrome, following total knee replacement. Of these, six cases had loss of function of one compartment, and the seventh required amputation. Delay in diagnosis and decompression was common to these cases. In five of these cases, the delay was thought to be due to use of postoperative epidural infusion for pain relief.

Very rarely, rhabdomyolysis has been reported, generally where tourniquet duration was longer than 4 hours.

Nerve injury

Neurological injuries after tourniquet use are the most common complication, and can be the most devastating. The incidence of nerve injury reported in the literature varies between 0.1-7.7%. This wide variation is thought to be due to underdiagnosis of nerve injury, because of limb

weakness postoperatively from muscle injury, as well as the often rapid recovery of the nerve.

Patients who have delayed recovery in the rehabilitation process are often perceived as lacking motivation or commitment. However, in such patients, delayed recovery may be due to a slowly resolving nerve injury, which has not been diagnosed. In such instances, nerve conduction studies are recommended. Nerve injury is due to mechanical compression and ischaemia, but most of the damage occurs directly under, and near, the edges of the cuff, due to myelin disturbance, and disruption of the nodes of Ranvier from mechanical pressure. Although longer tourniquet times are associated with increased risk of nerve injury, mechanical pressure plays a greater role.

The use of an Esmarch bandage, which generates pressures > 1 000 mmHg is associated with a higher incidence of nerve injury, than the pneumatic tourniquet. Thus an Esmarch bandage should not be used for limb exsanguination before cuff inflation.

Although common, the prognosis of nerve injuries is good. Permanent deficits are rare, and most recover within six months.

In the upper limb, the nerves most commonly affected are the radial > ulnar > median nerve. In the lower limb, the nerves most commonly affected are the peroneal > tibial nerve. Although femoral nerve injuries also occur, they are often underreported.

In Odsson and Finsen's series, a survey took place over a two-year period of 265 Norwegian orthopaedic surgeons, performing 63 484 operations under tourniquet. Only 15 neurological complications were reported (an incidence of 0.024%), two were permanent, and the remainder resolved within six months.

Horlocker and Hebl studied 1 166 knee replacements under tourniquet, with tourniquet times of > 120 minutes. A total of 129 neurological complications were noted (an incidence of 7.7%). The peroneal nerve was more commonly affected than the tibial nerve (85 vs. 44 cases). Ninety-three per cent of these reported complete neurological recovery, with 100% tibial nerve recovery, and 89% peroneal nerve recovery.

Postoperative neurological dysfunction was associated with younger age, longer tourniquet times (inflation pressures were similar), and preoperative flexion contracture > 20 degrees. It is thought that the increased incidence of postoperative nerve injury associated with younger age is due to a relative increase in tourniquet pressure, where a fixed inflation pressure is used, as it was in this study.

Younger patients have a lower systolic blood pressure (SBP). Therefore, there is a larger difference between

tourniquet inflation pressure and SBP, than there is for an elderly patient with a higher SBP.

Where tourniquet times were > 180 minutes, a longer duration of deflation interval was associated with a modest decrease in incidence of neurological injury.

Often peripheral nerve blocks are used in patients undergoing cruciate ligament repair, or total knee arthroplasty (TKA) under tourniquet. In such instances, it is of concern to the anaesthetist whether there is an increased incidence of peripheral nerve injury (PNI).

A study by Jacob et al tested the hypothesis that the risk of PNI is higher if regional anaesthesia is used during TKA. In their study, there was an incidence of 0.79% of PNI (97 cases in 12 329 patients). The risk of PNI after TKA was unchanged by the use of regional anaesthesia. However, in the rare situations in which PNI did occur, complete recovery was less likely if peripheral nerve blockade was performed.

The authors support the use of regional anaesthesia because of the known benefits, with no increased risk of PNI, but regional anaesthesia should possibly be avoided in instances in which there is increased risk of PNI, for example, very long procedures, or where there is a flexion deformity of > 20 degrees.

Vascular injury

Arterial injury after tourniquet use is rare, but the consequences can be catastrophic. Acute vascular insufficiency is thought to occur when mechanical pressure from the tourniquet damages atheromatous vessels, and causes plaque rupture. In a series by Insall and Windsor, only seven arterial injuries occurred in more than 5 000 knee arthroplasties, but three of these required amputation. It is recommended that tourniquet use in patients with peripheral vascular disease is avoided.

Skin injury

Chemical burns occur when alcohol-based solutions, used for skin preparation, seep beneath the tourniquet and are held against the skin under pressure. To avoid chemical burns beneath the tourniquet, it must be shielded from seepage with a water-repellent self-adhesive plastic drape, prior to skin preparation.

Pressure necrosis and friction burns are due to inadequate padding, bad application of the tourniquet, and movement of a fully inflated tourniquet over bare skin. Soft wrinkle-free padding must be used below the cuff.

In a study by Olivecrona et al, it was confirmed that an elastic stockinette under a pneumatic tourniquet cuff, offers the best protection. Ninety-two patients were randomised

to either two-layer elastic stockinette, cast padding, or no protective material beneath the cuff. Skin blisters developed beneath the tourniquet in 10 patients, in three where cast padding was used, and in seven where no padding was used. No blistering occurred in patients in whom used the elastic stockinette was used.

It has been shown that stretched sleeves made of two-layer tubular elastic material, and matched to the specific tourniquet cuffs, produce fewer, less severe wrinkles in the skin surface, compared with all other types of limb protection.

Intraoperative bleeding and tourniquet failure

Intraoperative bleeding may be due to incomplete exsanguination of the limb, or a poorly fitted or under-pressurised cuff. It may also be due to blood entering through the intramedullary vessels of long bones. In such instances, increasing the tourniquet pressure does not help.

Tourniquet pain

Inflation of a tourniquet is followed by the development of a dull aching pain after +/- 30-60 minutes. This manifests as an increase in heart rate and blood pressure in patients under general anaesthesia. This pain can occur, despite adequate regional anaesthesia.

The mechanism as to how such pain arises is thought to be due to selective pain transmission of unmyelinated, slowly conducting C fibres. These fibres are continuously stimulated by skin compression, with loss of inhibition at the dorsal horn by larger myelinated A delta fibres. The conduction in larger myelinated fibres is inhibited by mechanical compression by the tourniquet.

Tourniquet pain, which occurs under apparently adequate neuraxial anaesthesia, is thought to occur as C fibres are more resistant to local anaesthetic conduction block. Also, with time, as the level of the block and concentration of anaesthesia decreases, C fibres regain function faster than A fibres.

Various methods have been tried to decrease the incidence of tourniquet pain, but none are completely satisfactory, except tourniquet deflation.

Techniques used include:

- The addition of adrenaline, morphine, or clonidine, to the neuraxial block. The addition of morphine delays the onset of pain.
- Intravenous (IV) ketamine 0.1 mg/kg. The N-methyl d-aspartate (NMDA) antagonist decreases central sensitisation of C fibre stimulation.
- Preoperative gabapentin.
- Ipsilateral stellate ganglion block.

- IV/oral clonidine. It may cause increased blood pressure drop after tourniquet release.
- Emla® cream.
- Circumferential subcutaneous infiltration of local anaesthetic.
- Wider cuff with lower inflation pressure.

Systemic complications

Cardiovascular effects

All stages of tourniquet use impact on the cardiovascular system. These effects may be poorly tolerated in patients with poor cardiac reserve, and cardiac arrest after application of bilateral thigh tourniquets has been reported.

With limb exsanguination and tourniquet inflation, there is an increase in systemic vascular resistance (SVR), central venous pressure (CVP) and circulating blood volume by up to 15% (800 ml). This may cause circulatory overload, with cardiac failure in patients with poor reserve.

During the maintenance phase of inflation, there is a gradual increase in heart rate and blood pressure, thought to be due to tourniquet pain.

Following tourniquet deflation (reperfusion), there is a decrease in both CVP and mean arterial pressure (MAP), due to:

- The shift of blood volume back to the limb, initially with a transient, relative increase in blood volume back to the limb due to post-ischaemic reactive hyperaemia
- The release of ischaemic metabolites into the systemic circulation. They may also cause myocardial depression and cardiac arrest.

Pulmonary effects

An increase in end-tidal CO₂ occurs, following tourniquet release. This increase is greater with larger ischaemia times, and following deflation of lower-limb tourniquets. The duration of the increase is prolonged in mechanically ventilated patients, unless minute ventilation is increased.

An increased incidence of pulmonary emboli is seen following tourniquet use. Emboli occur after limb exsanguination, particularly with the Esmarch bandage, and also with tourniquet inflation and deflation.

There is also an increase of fat, air, and cement emboli, when the medullary cavity is instrumented, as with TKA.

Acute lung injury has been described after limb reperfusion.

Neurological effects

Following tourniquet deflation, there is an increase in cerebral blood flow, due to increase in PaCO₂, resulting in an increase in intracranial pressure. This is accompanied

by a decrease in SBP, with resultant decrease in cerebral perfusion pressure. These effects are disastrous in patients with brain injuries. Hyperventilation, after tourniquet deflation to maintain normocapnoea, may prevent an increase in intracranial pressure.

Haematological effects

There is no difference in incidence of deep vein thrombosis (DVT) in surgery on lower limbs performed with, or without, tourniquet.

Although initially, there is a hypercoagulable state (an increased platelet aggregation due to increased catecholamines and surgical stress response) with tourniquet inflation, afterwards, there is an increase in fibrinolytic activity, due to release of a tissue plasminogen activator, lasting up to 30 minutes. This results in activation of antithrombin III and protein C pathways, and may result in increased bleeding post-tourniquet release.

Recommendations for safe tourniquet use

Tourniquet cuff design

The widest cuff possible must be selected, as a wider cuff occludes at lower pressures. A contoured cuff occludes blood flow at lower inflation pressures, than a straight or cylindrical cuff of equivalent width.

In a study by Reilly et al, where standard cylindrical cuffs were used, a much higher inflation pressure was required to achieve limb occlusion pressure than that in the group where wide-contoured cuffs were used.

Limb exsanguination and underlying limb protection

Aggressive exsanguination with any device should be avoided, as there is an increased risk of disseminating tumour cells or infection, or of causing pulmonary emboli by dislodgement of DVT, or atheromatous plaque.

There is also a higher incidence of nerve injury associated with use of an Esmarch bandage, due to the very high pressures generated. It is recommended that exsanguination of the limb is carried out by limb elevation alone, as this is safe and easy to achieve. Recommendations are to elevate the arm at 90 degrees for five minutes, and the leg at 45 degrees for the same length of time.

Soft wrinkle-free padding must be used below the cuff. A double-layered elastic stockinette offers the best protection.

The skin must be shielded from the seepage of alcohol-based solutions beneath the tourniquet with a water-repellent, self-adhesive plastic drape applied prior to skin preparation, to prevent chemical burns.

Duration of tourniquet use

Tourniquet-related complications increase with length of time relating to usage. Therefore, all tourniquets should be inflated for the shortest time possible.

The maximum duration for which a tourniquet can be inflated continuously has not been precisely established. Most recommendations suggest an upper limit of 1.5-2 hours in healthy patients. It is generally accepted that a tourniquet that is used for longer than two hours should be deflated for 10-15 minutes every one to two hours to allow for limb reperfusion. However, there is no evidence to support this technique, and some authors feel there is no benefit in tourniquet release and reinflation if the total tourniquet time is less than three hours.

Tourniquet pressures

Tourniquet pressures should be kept to a minimum to limit tissue injury. Nerves are very susceptible to injury by mechanical pressure.

Orthopaedic surgeons follow two common practices with regard to inflation pressures:

- To inflate the tourniquet to a fixed pressure (usually 250 mmHg for the arm, and 300 mmHg for the thigh).
- To inflate to a fixed amount of pressure above SBP (usually 100 mmHg above SBP for the arm, and 100-150 mmHg above SBP for the thigh).

However, neither of these is ideal, and it is recommended that tourniquets are inflated to pressures based on limb occlusion pressure (LOP), or arterial occlusion pressure (AOP). The LOP is determined by gradually increasing the pressure in the tourniquet, while assessing distal arterial blood flow with a Doppler probe. The LOP is the pressure in the cuff at which the pulse disappears. It is recommended that the cuff is inflated to slightly above LOP.

Recommendations are as follows. If LOP is < 130 mmHg, then 40 mmHg is added, if LOP is 131-190 mmHg, then 60 mmHg is added, and if LOP is >190 mmHg, then 80 mmHg of pressure is added.

The AOP can also be estimated by using Graham's formula, which takes into account tourniquet size:

$$AOP = [(SBP - DBP)(Limb\ circumference) / 3(cuff\ width)] + DBP$$

Studies have shown that by using the AOP/LOP, the tourniquet pressures can be decreased by up to 20-40% in adults, and > 50% in children, so a young, slim, normotensive adult may require a cuff pressure < 200 mmHg.

Modern tourniquet systems are available which provide an automated estimation of the LOP for each patient, and which monitor LOP throughout surgery. They will also adjust

the inflation pressure following fluctuations in SBP and LOP during surgery, permitting individualised setting of safer tourniquet pressures throughout.

Contraindications to tourniquet use

Several relative contraindications to tourniquet use have been described in the literature.

These include:

- Severe atherosclerotic disease
- Severe crush injuries
- Head injury
- Peripheral neuropathy
- Severe infection in the limb
- Localised tumours
- Arteriovenous (AV) fistula
- DVT in the limb
- Rheumatoid arthritis, and other collagen vascular diseases with vasculitis
- Calcified vessels
- Poor skin condition of the limb
- Sickle cell disease.

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