Tourniquet application during anesthesia: "What we need to know?"

Kamal Kumar, Craig Railton, Qutaiba Tawfic

Department of Anesthesia and Perioperative Medicine, Schulich School of Medicine, Western University, London Health Sciences, Victoria Hospital, London, Ontario, Canada

Abstract

Tourniquets are routinely and safely used in limb surgeries throughout the world. Tourniquet application alters normal physiology. Healthy patients tolerate these physiological changes well, but the physiological changes may not be well-tolerated by patients with poor cardiac function. This review discusses the physiological changes associated with tourniquet use, safe practice and provides the latest updates regarding tourniquet use. A systematic literature search of PubMed, MEDLINE, ScienceDirect, and Google Scholar was done. The search results were limited to the randomized controlled trials and systemic reviews. The papers are summarized in this review.

Key words: Complications, deflation, limb surgeries, tourniquet, tourniquet inflation

Introduction

Tourniquet use is a common practice in orthopedic and plastic surgeries. They are compressive devices that occlude blood flow to the limbs to create bloodless surgical field and decrease the perioperative blood loss. They are also used for intravenous regional anesthesia (Bier's block) to prevent the central spread of local anesthetics. Tourniquet usage is associated with several complications and over the years it has undergone various modifications to improve the safety.[1] Its use has been associated with several physiological alterations that can affect patient outcome following surgery. The operating team including the anesthetist should therefore have correct knowledge about its application. This review discusses the physiological changes associated with tourniquet use and safety practices, and provides the latest updates regarding tourniquet use.

Address for correspondence: Dr. Kamal Kumar,
Department of Anesthesia and Perioperative Medicine,
Schulich School of Medicine, Western University, London Health
Sciences, Victoria Hospital, London, Ontario, Canada.
E-mail: drkamalcmc@gmail.com

History

The tourniquet was first used in ancient times as a life-saving and limb saving devise during injuries. However, tourniquet has been defined as a limb-threatening device in some occasions when it is misused. The history of using tourniquets belonged to the middle ages when a tight band was first used on injured soldiers at the Battle of Flanders in 1674. The use of tight bands continued to develop through many stages until we reached the modern design of tourniquet [Table 1].[1,2]

Definition of Tourniquets

A tourniquet is a constricting or compressing device used to control venous and arterial circulation to an extremity for a period of time.[3]

Types of tourniquets
Emergency tourniquets
A tightly tied band applied around a limb (upper or lower) to prevent severe blood loss from limb trauma during emergency.

Table 1: Some stages of development of tourniquet

1628: William Harvey, an English surgeon discovered and traced the human circulation

1674: Morel was first to wrap a tight band below and above the site of amputation to reduce bleeding

1718: Jean Louis Petit, a French surgeon, developed the mechanical twisting device and named it "Tourniquet" (derived from the French word "tourner" meaning to turn)

1864: Joseph Lister was the first to use a tourniquet to create a bloodless surgical field

1873: Johann von Esmarch developed a rubber bandage for exsanguination and tourniquet use

1904: A major breakthrough was Harvey Cushing's inflatable model, applied with compressed gas

1908: August Bier introduced the use of two Tourniquets for administering segmental anesthesia

1980: Modern electronic tourniquet systems also called computerized tourniquets or Microprocessor controlled tourniquets were invented by James McEwen

It should be used as a last resort to control bleeding. Emergency tourniquets are widely used by the military to save lives during combat.

Surgical tourniquets

Surgical tourniquets enable the surgeons to work in a bloodless operative field by preventing blood flow to a limb and allow surgical procedures to be performed with improved accuracy, safety, and speed. They have two basic designs - noninflatable and inflatable. Frequently the two types of tourniquets are used together in orthopedic and plastic surgery, such as in intravenous regional anesthesia (Bier block anesthesia).

Noninflatable (nonpneumatic) tourniquets

Noninflatable tourniquets are made of rubber or elastic cloth. Now-a-days, their surgical use alone is limited because they have been replaced by modern tourniquet systems.

Pneumatic tourniquet

Pneumatic tourniquets use compressed gas to inflate a bladder or cuff to occlude or restrict blood flow. A regulating device on the tourniquet machine can control the amount of cuff pressure exerted on the limb. The pressure is provided by an electrically driven pump or by a central compressed air supply.[3,4]

Components of pneumatic tourniquets

The five basic components are:
- An inflatable cuff (bladder)
- A compressed gas source
- A pressure display
- A pressure regulator
- Connection tubing.

Inflatable cuff

Pressure is exerted on the circumference of an extremity by means of compressed gas, which is introduced into a bladder within the tourniquet cuff. Different types of cuffs are available, and the appropriate choice is determined primarily by proper fit and surgical procedures. When selecting a cuff, the following criteria are considered:[4]

- Cuff location
- Single- versus dual-bladder design
- Cuff shape
- Cuff length
- Cuff width
- Disposable versus reusable cuffs
- Specialty applications
- Limb protection

The length and width of the tourniquet cuff should be individualized — considering the size and circumference of the patient's limb. The tourniquet cuff should overlap at least three inches but not more than 6 inches.[4] Too much overlap causes increased pressure and rolling or wrinkling of underlying soft tissue. Too small overlap compromises effective tourniquet inflation and can result in unexpected release or inadequate constriction.

The width of the cuff should be wider than half the limb's diameter. Wider cuffs minimize the risk of injury to underlying tissue by dispersing pressure over a greater surface area.[4] Wider cuffs have been found to consistently occlude blood flow at a lower pressure in adults and children.[4]

Tourniquets should be positioned on the limb at the point of the maximum circumference.[5,6] A soft padding should be placed around the limb before application of the tourniquet. It can help reduce wrinkling, pinching, and shearing of the soft tissues. The cuff tubing should be positioned on or near the lateral aspect of the extremity to avoid pressure on nerves and kinking of the tubing.

Tourniquet Cuff Pressure

The pressure to which a tourniquet cuff should be inflated depends on a number of variables: The patient's age, skin, blood pressure, shape and size of the extremity, and the dimensions of the cuff. The tourniquet pressure should be minimized in the effort to produce a bloodless surgical field. Lower pressures are thought to prevent injury of normal tissue. Despite many years of tourniquet use, the optimal inflation pressure to accomplish this objective is not yet

established by a research study. Surgical texts recommend cuff pressures of 200-300 mmHg for adults. Various methods have been implemented in an effort to lower effective cuff pressure:[7-13]

1. Double tourniquet technique, to change the point of compression[7]
2. Controlled hypotension to bring down systolic blood pressure can also be used to decrease direct cuff pressure against the tissue[8]
3. Doppler technique and pulse oximetry to confirm the absence of the arterial pulse to determine the minimum inflation pressure[9]
4. Tourniquet inflation based on limb occlusion pressure (LOP)[10,11]
5. Cuff pressure synchronization with systolic blood pressure.[11-13]

Limb occlusion pressure

LOP can be defined as the minimum pressure required to stop the flow of arterial blood into the limb distal to the cuff. LOP is determined by gradually increasing tourniquet pressure until distal blood flow is interrupted. According to the guidelines from the Association of Perioperative Registered Nurses,[14] cuff inflation pressure should be adjusted by adding a safety margin to the LOP as follows:

1. Add 40 mmHg for LOP <130 mmHg
2. Add 60 mmHg for LOP between 131 and 190 mmHg
3. Add 80 mmHg for LOP >190 mmHg
4. For pediatric patients, adding 50 mmHg has been recommended.

The LOP should be measured during preoperative check-up or when the blood pressure is stabilized after induction of anesthesia. The risk of tourniquet related complications can be significantly reduced by measuring the LOP and selecting cuff inflation pressures accordingly.[15] Best practice recommends that optimal cuff pressure should be based on the patient's systolic blood pressure or LOP.[16]

Inflation of the tourniquet cuff should be under the direction of the surgeon and coordinated with the anesthetist because it facilitates patient management during the rapid physiologic changes caused before and after limb exsanguination and cuff inflation.

Exsanguination before inflation of the tourniquet improves the quality of the bloodless field and minimizes pain associated with tourniquet use. It is normally done by limb elevation or using an elastic wrap of the extremity. Elastic wraps should not be used if any of the following is present: Infection, malignant tumor, fractures, or thrombi in the extremity. Application of the wrap can force the

thrombi, infection or malignant cells into the circulation. In these cases, exsanguination should be accomplished by extremity elevation alone. Exsanguination and the use of tourniquets are both controversial in patients with sickle cell disease.[17]

Pneumatic tourniquets should be inflated rapidly because rapid inflation occludes arteries and veins almost simultaneously preventing the filling of superficial veins before occlusion of arterial blood flow.

Inflation or occlusion time

Inflation time should be kept to a minimum to minimize risks to the patient. Safe tourniquet inflation time has not been accurately determined. The time varies with the patient's age, physical status, and the vascular supply to the extremity. No strict guidelines exit. A safe time limit of 1-3 h has been described. It has been recommended to assess the operative situation at 2 h and if the anticipated duration is >2.5 h then use a 10-min deflation interval at that point and at subsequent 1-h intervals.[18] In pediatric patients, inflation time of <75 min has been recommended for lower extremities.[19,20]

Cuff deflation

Tourniquet deflation causes release of anaerobic metabolites into the systemic circulation causing hypotension, metabolic acidosis, hyperkalemia, myoglobulinemia, myoglobinuria, and possible renal failure. It is also known as "myonephropathic metabolic syndrome," and it depends on the size of the extremity, duration of tourniquet time, and overall physiologic status of the patient.[20]

Tourniquet related complications

Tourniquet related complications or side effects are either local or systemic.

Localized complications now follow.

Nerve injuries

Nerve injuries related to tourniquet application range from paresthesia to paralysis. Nerve tissues are less vulnerable to acute injury compared to skeletal muscle. The incidence is estimated to be 1:6200 for the upper limb and 1:3700 for the lower limb. The overall incidence of permanent injury is 0.032%.[21]

The nerve injury is maximum at the proximal and distal edges of the cuff where the shear stress is greatest. Nerve injuries are more common in the upper limb than lower limb. The most common upper limb nerve injury is that of radial nerve, followed by the ulnar and median nerves. The

common peroneal nerve is the most commonly injured lower extremity nerve.

The pathophysiologic cause of nerve injury following tourniquet is thought to be a combination of compression and ischemia. It is thought compression plays a more important role. Compression of the nerve by the cuff causes intraneural microvascular abnormalities in the parts of the nerve adjacent to the cuff. Edema results and leads to compromised tissue nutrition and axonal degeneration. Nerve injuries are more common with the use of Esmarch bandage than with a pneumatic tourniquet. The Esmarch bandage can generate pressures as high as 1000 mmHg.[22] The prognosis of tourniquet induced nerve injuries is generally good-permanent deficits are rare, and most injuries will heal spontaneously within 6 months.[21,22]

Muscle injury
Muscle injury following the application of the tourniquet is due to the combined effect of ischemia and mechanical deformation of the tissue. The ischemia and compression lead to metabolic and microvascular changes. These changes become more profound as the duration of the tourniquet inflation increases. Intracellular concentrations of creatine phosphate, glycogen, oxygen, and ATP are exhausted by 3 h.[22,23]

Tourniquet induced ischemia and reperfusion generate hydrogen peroxide and cause increased xanthine oxidase activity in local and systemic blood which contributes to the injury of skeletal muscle, myocardium, kidneys, and lungs after ischemia and reperfusion.

Vascular injury
Direct vascular injury is an uncommon complication of tourniquet use. It occurs most commonly in children, obese, elderly, and patients with peripheral vascular disease.

Skin injury
Skin injuries are uncommon, but excessive tourniquet time or poorly placed tourniquets may result in cutaneous abrasions, blisters and even pressure necrosis. The highest risk of skin injury occurs in: Children, obese, elderly, and patients with peripheral vascular disease.

Systemic Effects

Cardiovascular effects
Cardiovascular changes occur during all phases of tourniquet application from exsanguination to deflation. Limb exsanguination and tourniquet inflation increase blood volume and systemic vascular resistance that ultimately cause a transient increase in central venous pressure. This fluid shift can augment central venous pressure and also blood volume by 15% that can be up to 800 ml following exsanguination of both legs.[2,24,25] Hemodynamic changes associated with tourniquet use are minimal in healthy patients, but patients with poor cardiac function may not tolerate these changes. Heart rate, systolic, and diastolic pressures may increase after 30-60 min of tourniquet inflation due to ischemia and tourniquet pain. These changes persist until tourniquet deflation and poorly respond to analgesic drugs or increasing the depth of anesthesia. Many interventions have been reported to reduce cardiovascular stress:[24-32] Ketamine, dexmedetomidine, magnesium sulfate, clonidine, and remifentanil infusion.

Tourniquet deflation is a critical stage because it causes sudden drop in central venous pressure and mean arterial pressures. Cardiac arrests have been reported following cuff deflation.[24-27] These hemodynamic changes are due to the combination of a shift in blood volume back into the limb and washout of metabolites from the ischemic limb into the systemic circulation. Hemodynamic changes are more marked with the simultaneous use of tourniquets on both lower limbs.

Respiratory effects
Respiratory changes are rare and mainly seen during the deflation of the tourniquet. It is associated with transient increase in end-tidal carbon dioxide ($EtCO_2$) tension due to efflux of hypercapnic venous blood and metabolites into the systemic circulation.[24,25] The increase in $EtCO_2$ is related to the duration of ischemia. $EtCO_2$ increase is also greater with the lower limb tourniquet and in men than in women, because of a man's greater muscle bulk. The $EtCO_2$ peaks at 1-3 min, returning to baseline at 10-13 min in a spontaneously breathing patient but takes longer in mechanically ventilated patients unless the minute volume is increased.[25-27]

Cerebral circulatory effects
Cerebral circulatory changes are secondary to increase in $EtCO_2$ after tourniquet deflation that increases the cerebral blood flow in 2 min and returns to baseline within 10 min. Patients with reduced intracranial compliance may be at higher risk for adverse effects related to the increase in cerebral blood flow. Maintaining normocapnia can prevent this increase in cerebral blood flow during deflation.[33-35]

Hematological effects
Tourniquet use induces changes in both coagulability and fibrinolysis. Tourniquet inflation during surgery is associated with a hypercoagulable state that is due to increased platelet aggregation and stimulation of coagulation factors caused by

tissue damage and catecholamines released in response to pain from surgery and the tourniquet application.[36-39]

There is a brief period of increased fibrinolytic activity due to the release of tissue plasminogen activator, activating the anti-thrombin III and thrombomodulin — protein C anticoagulant system after the deflation of the tourniquet. This acts as one of the contributors in posttourniquet bleeding. The increase in fibrinolysis is maximal at 15 min and returns to preoperative levels within 30 min of tourniquet release.[39,40]

Tourniquet use in hematological disorders such as sickle cell disorder is controversial.[17] In sickle cell disease, sickling is precipitated by circulatory stasis, acidosis, and hypoxemia, all of which happen during the use of a tourniquet. Available evidence suggests that with proper necessary precautions, tourniquets may be used with no relative harmful effects in most patients with sickle cell disease.[41]

Metabolic Changes

Limb occlusion causes metabolic changes in the ischemic limb that include: Increased lactic acid, $PaCO_2$ and potassium levels, and decreased levels of PaO_2, and pH. Toxic metabolites produce pathophysiological changes when released into the general circulation.[10,22-24] The degree of these changes correlates with the duration of ischemia. All of these changes are fully reversed within 30 min of tourniquet deflation. Metabolic changes are more pronounced when bilateral tourniquets are used.

Temperature Changes

Tourniquet inflation and deflation cause alteration of body temperature. Core body temperature gradually increases following tourniquet application as the available surface area for heat loss decreases resulting in less heat transfer from the central to the peripheral compartment. Deflation leads to a transient fall in core temperature due to the redistribution of body heat and hypothermic blood from the ischemic limb. Maintenance of core body normothermia during surgery reduces this decline in temperature.[42,43]

Tourniquet Pain

Tourniquet pain is described as a poorly localized, dull, tight, aching sensation at the site of tourniquet application. During general anesthesia, it manifests as an increase in heart rate and mean arterial pressure. It is more common under general anesthesia (53-67%) and occurs most often during lower-limb surgeries. The exact etiology is unclear, but it is thought to be due to a cutaneous neural mechanism.[44] The pain is thought

to be mediated by the unmyelinated, slow conducting C fibers that are usually inhibited by the A-delta fibers. The A-delta fibers are blocked by mechanical compression after about 30 min, while the C fibers continue to function. Tourniquet compression leads to release of prostaglandins by the injured cells. These prostaglandins increase pain perception by sensitizing and exciting pain receptors. Also, limb ischemia causes central sensitization via NMDA receptor activation due to repeated nociceptive afferent input from the affected limb.[45,46]

Tourniquet pain has important impacts on anesthesia. Many techniques[27] like application of EMLA cream, infiltration with local anesthetics, use of wider cuff with lower inflation pressure, addition of opioids, clonidine, epinephrine along with local anesthetics in spinal block have been tried in order to decrease the incidence or severity of this pain but none has attained complete success in pain relief. Intravenous drugs,[24-32,47] ketamine, dexmedetomidine, magnesium sulfate, clonidine remifentanil infusions have also been studied, and the only thing that works reliably is tourniquet deflation.

Pharmacological Effects

Tourniquet inflation isolates the limb from the rest of the body and can alter the volume of distribution of some medications resulting in alteration of the pharmacokinetics of anesthetic drugs. The clinical significance of such variation in drug pharmacokinetics has not been studied but is thought to be limited.

The time interval between antibiotic administration and tourniquet inflation is important for antibiotic prophylaxis during surgery, but there are no specific guidelines. Orthopedic surgery guidelines suggests that the antibiotic must be completely infused prior to the inflation of the tourniquet.[48] The clinical evidence has suggested that prophylactic antibiotics need to be given at least 5-10 min before tourniquet inflation to allow good tissue penetration.[48-50]

Contraindications

There are no absolute contraindications to tourniquet application, but adequate care should be taken in the following group of patients:
1. Severe peripheral vascular disease
2. Sickle cell disease
3. Severe crush injury
4. Diabetic neuropathic patients
5. Patients with history of deep vein thrombosis and pulmonary embolism

Conclusion

Arterial tourniquets are widely used in surgery, and can have significant systemic as well as local effects on the body. It is therefore important for us to be aware of the physiological effects of tourniquets and there implications in anesthesia as they may affect any system in the body. Complications are rare, but if they occur, can be devastating.

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Conflicts of interest
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CONFERENCE CALENDAR October-December 2016

Name of conference	Dates	Venue	Name of organising Secretary with contact details
Difficult Airway Society Annual Meeting 2016 (DAS 2016)	November, 16th-18th, 2016	Riviera International Centre, Torquay	https://www.das.uk.com/meetings
64th Annual National Conference of Indian Society of Anaesthesiologists ISACON 2016	November, 25th-29th, 2016	Punjab Agricultural University Campus, Ludhiana	Dr. Sunil Katyal, Organizing Secretary 19-H, Ashok Vihar, Rishi Nagar, Ludhiana -141 001, Punjab, India Mobile: +91 9814030552, E-mail ID: katyalsunilmd@gmail.com Web: www.isacon2016.com
Anaesthesiology 69th Postgraduate Assembly 2016 (NYSSA 2016)	December 9th-13th, 2016	Marriott Marquis, New York, USA	http://pganyc.weebly.com/ THE NEW YORK STATE SOCIETY OF ANESTHESIOLOGISTS, INC. 110 East 40th Street, Suite 300, New York, NY 10016 USA Telephone: 1-212-867-7140 Fax: 1-212-867-7153International: +00 followed by number HQ@nyssa-pga.org
RACE 2017 Ramachandra Anaesthesia Continuing Education	February 10th-12th, 2017	Sri Ramachanda University, Porur, Chennai - 116, Tamil Nadu, India	RACE Secretariat, A6 OR Complex, Department of Anesthesiology, Critical Care and Pain Medicine, Sri Ramachanda University, Porur, Chennai - 116, Tamil Nadu, India Phone+91 9042606596 E-mail: race.srmc@gmail.co For Online Registration Log on to http://www.raceanes.com For further details mail us at race.srmc@gmail.com
Mayo Clinic Symposium on Anesthesia and Perioperative Medicine 2017	February 15th-18th, 2017	Fairmont Scottsdale Princess 7575 E. Princess Drive Scottsdale, AZ 85255 United States	https://ce.mayo.edu/content/ mayo-clinic-symposium-anesthesia-and-perioperative-medicine-2017 cme@mayo.edu. https://ce.mayo.edu/content/contact-us