

Tourniquet in Plastic Surgery

C.N. Yogishwarappa and Abhishek Vijayakumar*

The Bangalore Medical College and Research Institute, Krishna Rajendra Road, Fort, Kalasipalyam, Bengaluru, Karnataka 560002, India

Abstract: Tourniquet is invaluable instrument to plastic, hand and orthopedic surgeon. It helps create a bloodless field for easy operation and reduces operative time. The advantages of tourniquet is no without its share of complication including nerve and skin injuries and devastating vascular lesions leading to amputation or death. A thorough understanding of the local and systemic effect of tourniquet is essential to minimize the complication. Various physical and pharmacological modifications reduce the reperfusion injury and also help increase tourniquet time. This review discusses the principle, physiology and complications of tourniquet.

Keywords: Tourniquet, Limb occlusion pressure, Reperfusion injury, Nerve palsies, Limb protector sleeves.

1. INTRODUCTION

1.1. History

The first records to prevent arterial bleeding has been ascribed to Sushruta, the father of surgical art and science, in 600 B.C he pressed the arteries with pieces of leather that he made himself and it is said that he had used a device in which we now call the tourniquet [1]. The tourniquet was first used in 200 BC and continued up to 500 A.C during Roman emperors' era [2]. Galen advocated against the use of tourniquet because it increased bleeding and probably caused low blood pressure that suppressed the venous return [3]. In 1718 Jean-Louis Petit displayed his invention at the Royal Scientific Academy of Paris and used the word "tourniquet à vis", which was derived from 'turnere' a vis', a French word that means turning. Lister probably was the first surgeon who used a bloodless field created by a tourniquet in a surgery other than for amputation. In his case of a wrist ganglion excision he opined that the limb must be kept upright for three minutes before using a tourniquet for the blood to exit [4]. The next tourniquet was introduced by Johann Friedrich August von Esmarch was a flat rubber bandage [5]. He proposed that the rubber bandage be avoided if the soft tissues contain pus as this was likely to spread the infection, which is now accepted as a rule. Harvey Cushing invented the pneumatic tourniquet being inspired from blood barometer after disadvantages with the Esmarch band because of its possible neurologic complications. In 1984 Mac Evan, a biotechnology engineer from Vancouver invented a micro computerized tourniquet systems [6]. The newer systems have the ability to measure pressure and tourniquet time

continuously and prevent sudden drops in tourniquet pressure because of a probable loss of the electric supply or operator mistakes. It can also measure the mean occlusion pressure for every patient.

1.2. Definition of Tourniquets

A tourniquet can be defined as a constricting or compressing device used to control venous and arterial circulation to an extremity for a period of time. Pressure is applied circumferentially upon the skin and underlying tissues of a limb; this pressure is transferred to the walls of vessels, causing them to become temporarily occluded. In surgical settings, a tourniquet is used following exsanguination to produce a relatively bloodless operative field.

1.3. Types of Tourniquets

Two distinct types of tourniquets are found in the surgical setting:

- Noninflatable (nonpneumatic) tourniquets constructed of rubber or elasticized cloth.
- Pneumatic tourniquets, which have cuffs that are inflated by compressed gas.

2. CLINICAL INDICATIONS

Use tourniquet may be luxury and necessity surgeons. Tourniquet is indispensable in hand surgeries to attain a blood less field. In burn surgeries it is essential to limit blood loss and reduce transfusion rates. Other indications include:

- Repair of burn contractures.
- Excision of lesions or tumors of the limbs.
- Split - thickness skin grafts on burned patients.

*Address correspondence to this author at #128 Vijay Doctors Colony Konanakunte Bangalore 560062, India; Tel: 9980579089; E-mail: abhishekbmc@yahoo.co.in

- Repair of bone, cartilage, tendons, nerves, or blood vessels.
- Resection of invasive tumors or lesions.
- Repair of congenital anomalies (e.g., syndactyly or polydactyly).
- Amputations or replantations.

3. CONTRAINDICATIONS TO TOURNIQUET USE

The final decision on whether or not to use a tourniquet depends on the surgeon. Some of the contraindications are:

- Open fractures of lower limbs.
- Post - traumatic lengthy hand reconstruction.
- Severe crushing injuries.
- Severe hypertension
- Compromised circulation (e.g., peripheral artery disease).
- Diabetes mellitus.
- Elbow surgery (with concomitant excess swelling).

The use of tourniquets is controversial in patients with sickle cell disease. Sickle cell disease is common in Africa. The erythrocytes form a crescent-like or sickle shape when deprived of oxygen. Blood that remains in a limb distal to a tourniquet prone to sickle. Tourniquets induce the three most critical conditions known to produce sickling: circulatory stasis, acidosis and hypoxia. Ludham and Jellis [7] from Africa pointed out that a bloodless field may shorten the surgery time and lessen blood loss and crucial especially if no blood is available for transfusion.

Also blood that remains in the limb may sickle causing serious effects. With careful monitoring of systemic pO₂ by pulse oximetry, Ludham and Jellis showed no marked lowering after deflation of the tourniquet in patients with sickle cell disease. The benefits offered by use of a tourniquet need to be balanced against the risks and a decision should be made for each individual operation. Careful exsanguination is the key to safety. In a study by Stein and Urbaniak [8] 21 patients carrying the sickle cell gene who underwent 29 operations under tourniquet there was no statistically significant increased incidence of complications when compared with a control patients without the sickle cell trait and who had similar operations.

4. EFFECT OF TOURNIQUET AND ITS CLINICAL IMPLICATION

Tourniquet has varied local and systemic effects. Understanding the systemic effects and ways to modulate it can help in increasing tourniquet time safely (Table 1).

4.1. REPERFUSION INJURY

In Ischaemic injury the cell is deprived of the energy needed to maintain ionic gradients and homeostasis, and failure of enzyme systems leads to cell death. A tissue, which has been exposed to a period of ischemia when reperfused undergoes a series of changes which may be detrimental to the cells. Reperfusion injury is mediated by the interaction of various free radicals, endothelial factors and neutrophils. The return of toxic metabolites to the systemic circulation may also have serious metabolic effects reperfusion may also induce further local tissue injury. Local and systemic damage are associated with neutrophil accumulation in the microvasculature. Activated neutrophils adhere migrate across the endothelium and cause cellular destruction by releasing various free radicals, proteolytic enzymes and peroxidases. Of the various free-radical are generated, hydroxyl radical is the most reactive species, which is capable of damaging proteins, DNA and lipids. Lipid peroxidation disintegrates cell membranes causing swelling of cells. Swelling following tourniquet application contributes to post-operative pain. The increase in vascular permeability is caused by inflammatory response to free-radical action on endothelial cells. Fluid leak is associated with increased interstitial pressure within the fascial compartments of the upper and lower limbs, which causes compression of the microvasculature and impairment of the blood supply [28]. Heparin administration before application of the tourniquet has been associated with reduction of swelling, suggesting that some intravascular thrombosis is probably involved in the production of swelling.

4.2. Modifying Ischemia-Reperfusion

4.2.1. Pharmacological Modification

Pharmacological modification of ischemia-reperfusion injury mainly involves reducing the production and effects of superoxide and secondary radicals. Generation of superoxide has been reduced using allopurinol, a xanthine oxidase inhibitor, whereas secondary production of the more cytotoxic hydroxyl radical is reduced by iron chelator desferrioxamine [29]. Intracellular accumulation of calcium from external source or from damaged sarcoplasmic reticulum has been implicated

Table 1: Physiological Changes with Tourniquet and Its Clinical Implications

System	Effect	Complication	Precautions
Muscle	<ul style="list-style-type: none"> • Both compression and ischemic changes [9]. • Lactic acid buildup with mitochondrial changes [10]. • Reduced contractile property of underlying muscles [11]. • Phagocytic infiltration and increased vascular permeability [12]. 	<ul style="list-style-type: none"> • Post tourniquet syndrome 	<ul style="list-style-type: none"> • Reduce duration of tourniquet • Reduce pressure
Nerve	<ul style="list-style-type: none"> • Conduction block • Displacement of nodes of Ranvier between compressed and uncompressed regions [13]. • Paranodal demyelination [14]. 	<ul style="list-style-type: none"> • Tourniquet palsy 	<ul style="list-style-type: none"> • Decreased pressure • Increase in width of cuff • Use of limb contoured cuffs
Skin	<ul style="list-style-type: none"> • Pressure necrosis friction burns [15]. 	<ul style="list-style-type: none"> • Chemical burns 	<ul style="list-style-type: none"> • Use of skin protective stockinet • Avoid alcohol based disinfectants
Cardiovascular system	<ul style="list-style-type: none"> • Increase in Central venous pressure and arterial pressure on inflation and fall in pressure on deflation [16,17]. • Micro emboli on deflation [18,19]. 	<ul style="list-style-type: none"> • Intraoperative hypertension • Inadequate exsanguination of the limb undergoing surgery coupled with stasis and cooling may contribute to fresh thrombus formation. 	<ul style="list-style-type: none"> • Use of ketamine at induction [20] • Through exsanguination of limb
Respiratory system	<ul style="list-style-type: none"> • Increase in end-tidal carbon dioxide concentration on deflation and returns to normal by 3-6min [21]. 		
Metabolic system	<ul style="list-style-type: none"> • Increased plasma K⁺ • Increased lactic acid and carbondioxide • Metabolic acidosis takes 20-40min to return normal [22]. 	<ul style="list-style-type: none"> • Buffering capacity is reduced by anaemia, hypovolaemia, metabolic acidosis or pre-existing vascular disease. • Prior cardiac diseases myocardium may be sensitised to catecholamines by anaesthetic agents causing arrhythmias in response to hyperkalemia. 	
Central nervous system	<ul style="list-style-type: none"> • Increase in cerebral blood flow and raise in intracranial pressure on deflation [23]. 		
Hematological	<ul style="list-style-type: none"> • Hypercoagulable state on inflation due to Increased platelet aggregation caused by catecholamines released in response to pain. • Increased fibrinolytic activity lasting 15-30min following deflation due to release of tissue plasminogen activator from vasa vasorum in response to ischemia [24,25]. 	<ul style="list-style-type: none"> • Increased bleeding on deflation. 	
Temperature	<ul style="list-style-type: none"> • Increase in core temperature due to decreased peripheral circulation [26]. • Decreased limb temperature by 3-4 degree [27]. 	<ul style="list-style-type: none"> • A marked rise in temperature may cause the anaesthetist concern about the possibility of malignant hyperthermia. • Drying of tissues 	

in Post ischemic injury. Calcium-release modulators such as dantrolene have been shown to provide partial protection against reperfusion injury [30]. Treatment with dantrolene sodium (4 mg/h) throughout the periods tourniquet and after removal was found to preserve the ultrastructural appearance of the quadriceps, soleus

and anterior tibial muscles. In the same study in animals depot methylprednisolone by a single 8-mg intramuscular injection led to preservation of the structure of tibialis anterior muscle fibres on both light and electron microscopy. High-dose continuous intravenous infusion with ascorbic acid (80 mg/h) throughout the period of

tourniquet application preserved the structure of the muscle [31].

4.2.2. Physical Modification

The concept using breathing periods represents an attempt to reduce ischaemic injury. This involves releasing the tourniquet after fixed period of ischemia to allow reperfusion, with the aim of returning tissue to its pre-ischaemic state before limb is subjected to a further period of ischemia. With knowledge of the ischemia-reperfusion syndrome, the use of breathing periods is illogical, as reperfusion is now recognized as a major cause of damage to limbs after ischemia. Continued damage by free-radical-mediated mechanisms is likely even after the biochemistry of the venous blood returns to normal equilibrium. Animal studies have suggested that allowing reperfusion may actually increase the amount of damage to the ischaemic limb in certain structures [32].

4.2.3. Hypothermia

The beneficial effects of hypothermia on the survival of ischaemic tissue have been shown in various studies. The underlying basis for protection is thought to be a reduction in the rate of cellular metabolism and may influence both ischemia and reperfusion mechanisms of injury. In a study by Irving [33] in pigs it was seen that Significant slowing of metabolism in hypothermic ischemic limbs through measurement of high levels of muscle glycogen and phosphofructose. Also the rate of return to normal levels of serum lactate, serum potassium and pH in hypothermic limbs suggested less tissue damage and a lower oxygen debt. Nayagam [34] carried out a randomized trial of the role of hypothermia in a series of 19 patients undergoing knee replacements. The effect of tourniquet ischemia on muscle was considered separately from reperfusion injury. The effect of preoperative limb cooling was assessed using clinical variables as well as biochemical assays of tissue samples. The effect of preoperative cooling on reperfusion is clear as there is a significant reduction in the loss of magnesium and potassium. Patients who had preoperative cooling lost a significantly smaller amount of blood (P 0.05). This difference may be due to persistent vasoconstriction in the cooled group even after the release of the tourniquet. This was seen even upto 20 minutes after release of the tourniquet. The difference in blood loss was approximately one unit of blood and may affect the decision not to transfuse. With regard to postoperative pain, there was a significant difference in visual analogue scores measured eight and 24 hours postoperatively.

4.2.4. Ischaemic Preconditioning of Skeletal Muscle

Ischaemic preconditioning is a process by which exposure of a tissue to a short period of (non-damaging) ischaemic stress leads to resistance to the deleterious effects of a subsequent prolonged ischaemic stress. Exposure of the hind limb to a five-minute period of ischemia and a five-minute period of reperfusion significantly protected the tibialis anterior muscle against the structural damage induced by a subsequent period of four hours of limb ischemia and one hour of reperfusion [35,36].

This protection was seen on examination of muscle by both light and electron microscopy. Duration of times of prior ischemia had no effect. The protective effects of preconditioning could to be reproduced by infusion of adenosine to animals immediately before the four-hour period of ischemia. This indicates a potential mechanism by which skeletal muscle may be preconditioned against damage of ischemia as adenosine inhibits free-radical production from activated neutrophils via a receptor-mediated mechanism [37]. The use of breathing periods can now be abandoned and replaced by perioperative pharmacological protection such as intravenous adenosine but further studies are required.

4.2.5. Exsanguination

In a study by Distefano *et al.* [38] using impedance plethysmography it was found that the maximal decrease in limb volume by elevation at 45 degrees occurred after 15–20 seconds, with no noticeable change thereafter. Warren *et al.* [39] measured changes of circumference of the limb with mercury in silastic strain gauges and found that the optimal time for elevation was five minutes. For the maximal effect it was suggested that the upper limb should be elevated at 90 degrees; for the lower limb 45 degrees of elevation, since further elevation was likely to kink the femoral vein due to the flexion of the hip. Using a gamma-camera technique and the injection of autologous 99m technetium-labelled erythrocytes, Blond and colleagues showed that there was little change in the reduction of blood volume of the lower limb at 60 degrees with an increase of the duration of elevation [40,41]. The results after half a minute were 45%, one minute 45%, two minutes 43%, four minutes 44%, six minutes 43%, and ten minutes 44%. This pattern was also seen in the upper limb.

4.2.6. External Compression

External compression in addition to elevation has been shown to improve the degree of exsanguinations.

It is however contraindicated in patients who have a suspected infected or malignant lesion. The use of an Esmarch bandage or manual exsanguination are more effective than elevation alone. Usage of Esmarch bandage is time-consuming and can damage the skin over a fracture or the atrophic skin of a patient with rheumatoid arthritis. It can also detach pre-existing venous thromboses and produce pulmonary emboli [42-44]. The need for control of the pressure that is applied has led to the development of appliances such as the Rhys-Davies Exsanguinator [45]. This is an inflated elastic cylinder that is rolled on to the limb. As the exsanguinator is applied, the pressure within the sleeve increases. External methods of exsanguination reduce limb volume by forcing blood from it.

5. COMPLICATIONS

Use of tourniquet may damage any of the tissues of a limb. Complications often have medicolegal implications. The most common problems are pain, nerve lesions, burns, compartment syndrome, delayed wound healing or even amputation.

The most common complication is tourniquet pain that may be the result of mechanical pressure and ischemia reperfusion mechanism. Study by Crews *et al.* it was observed that pain was not related to cuff width and tourniquet pressure [46] but study by Hagenouw *et al.* showed that the use of lower width cuffs results in milder pain, which is induced for a longer time [47]. Local anaesthesia with lidocaine may reduce the pain alternatively local 5% lidocaine; and prilocaine cream has same efficacy and associated with less patient discomfort [48]. Usage of gabapentin [49], ketamine [50], dexamethasone, and ketorolac [51] may lead to more efficient pain reduction.

5.1. Damage to Nerves

The incidence of peripheral nerve lesions reported are one in 5000 for the arm and one in 13 000 for the leg [52]. The arm palsies are of two main groups: the largest group involved median, ulnar and radial nerves below the tourniquet, while the slightly smaller group comprised isolated radial nerve lesions. The injuries occurred with both Esmarch bandages and pneumatic cuffs. Majority patients have full recovery. The approximate time for recovery was four to five months, although most palsies were transient and others required up to 12 months to disappear. Larger fibres are most susceptible to pressure. There is relative sparing of sensory nerves compared with motor nerves. Small

diameter fibres are spared preserving pain and temperature sensation and autonomic function. Because of the localised pathology most palsies heal spontaneously in less than six months and permanent deficits are rare [53,54].

Sensory defects are usually minor and tend to recover more rapidly than motor deficits. The main cause of tourniquet paralysis is excessive pressure [55]. Some conditions the nerves may be unusually susceptible to pressure [56] like neuropathy due to rheumatoid arthritis, alcohol or diabetes. Wasting of muscles may reduce the protection provided by muscles. Most lesions occur in the upper limb, where muscle bulk is less. The radial nerve is the most vulnerable followed by the median and ulnar nerves. The radial nerve is in the spiral groove adjacent to the humerus and therefore at highest risk of compression [57]. Saunders *et al.* observed that nerve injuries following the use of inflatable cuffs on the lower limb are more common than is generally thought [58].

Postoperative weakness of the quadriceps may be due to pressure on the femoral nerve and not simply disuse atrophy. In a study by Saunders *et al.* followed 48 consecutive patients after arthrotomy with postoperative electromyography (EMG) of the quadriceps muscles. They found in cases where the duration of surgery exceeded one hour, EMG changes were as high as 85%. Abnormal EMGs have also been noted in 72% of patients following meniscectomy 10–45 days after operation [59].

The duration of ischaemia does correlate with occurrence of the nerve lesion, which is primarily the result of compression. Variations in time are related to differences in the magnitude of the deforming force and the internal structure of the nerve at the site of compression [60]. Ochoa *et al.* [61] observed that most cases of nerve damage were limited to the portion of the nerve beneath and near the edges of the cuff. They found that compressive neurapraxia more than ischemic neuropathy or muscle damage was the underlying cause of tourniquet paralysis and showed that compression of the large myelinated fibers cause displacement of the node of Ranvier from its position under the Schwann-cell junction. This was accompanied by stretching of the paranodal myelin proximal to node and invagination of the paranodal myelin on the distal end. The nodal axolemma were identified as far as 300 mm from its normal position under the Schwann-cell junction, causing partial or complete rupture of the stretched paranodal myelin. The nodal displacement was

maximal under the edges of the cuff where the applied pressure gradient was greatest. There was near complete sparing under the center of the cuff, and the direction of displacement was away from the cuff toward the uncompressed tissue.

Tourniquet paralysis may result from both excessive or insufficient pressure, but the insufficient pressure is considered more dangerous, resulting in passive congestion with possible irreversible functional loss. Persons with lax, loose skin (e.g., the elderly), or persons with large amounts of subcutaneous tissue in cone-shaped limbs are subject to nerve and tissue injury from a shearing force created by an improperly fitting cuff. Most often, shearing occurs at the proximal edge of the cuff. Risk of shearing-related injury may be reduced by selecting a contoured cuff (which fits the limb taper) and a matching limb protection sleeve.

5.2. Post - Tourniquet Syndrome

Post-tourniquet syndrome (PTS) is manifested by prolonged postoperative swelling of the extremity. Most common cause of post-tourniquet swelling is caused by blood returning to the limb after the release of the tourniquet (hyperemia). Other causes is postischemic reactive hyperemia due to increase of blood to restore normal acid-base balance in tissue. Further swelling due to edema or a postoperative hematoma may also occur. Post-tourniquet syndrome is characterized by edema, pallor, stiffness, weakness without paralysis, and subjective numbness. PTS is thought to be due to prolonged ischemia rather than the direct mechanical effect of the tourniquet on the muscle. The tourniquet induces neuromuscular injury by causing ischemia in the tissues distal to the tourniquet, and by compression and ischemia in tissues beneath the cuff.

Postoperative weakness, edema, stiffness, dysesthesia, and pain could be falsely attributed to surgical trauma or to lack of patient motivation if the surgeon does not have an adequate index of suspicion of tourniquet-related neuromuscular injury. Studies have demonstrated EMG abnormalities in extremities treated with a routine pneumatic tourniquet [11]. These neurophysiologic changes may be associated with weakness of the involved extremity and a longer clinical recovery time; in fact, postoperative EMG abnormalities persist as long as 5 months in some cases. Studies suggest that the extent of skeletal muscle injury beneath the tourniquet is related to a complex interaction of the cuff pressure and duration [10].

The PTS occurs in patients in whom tourniquets was applied for a prolonged time and also in patients whose tourniquet cuff pressures were insufficient to prevent arterial inflow while preventing venous outflow. Under inflation of the tourniquet cuff is a particular risk in elderly patients who frequently have extensive calcification of the major arteries, which require a greater tourniquet pressure. Rheumatoid arthritis patients on steroid treatment experience the same problem in which a bloodless field cannot be obtained because of steroid-induced vascular calcification. Because of the significance of postoperative bleeding, patients with prolonged clotting times also are at risk for post-tourniquet syndrome.

5.3. Rhabdomyolysis

Rhabdomyolysis is the destruction of skeletal muscle, which may occur rarely. High levels of myoglobin result in acute renal failure. Many of the clinical features are non-specific, but pyrexia, pain and tenderness at the site of tourniquet, oedema, haemorrhagic discoloration. Other features are turbid urine, elevation of serum creatinine phosphokinase and lactate dehydrogenase. The serum creatine, urea, urate and phosphate and potassium levels are raised whereas sodium and calcium concentrates fall. Myoglobin is deposited in the distal convoluted tubule, ultimately causing occlusion. This may lead to renal failure, but other factors such as anoxic renal tubules may be secondary. In severe cases, haemodialysis may be necessary [62].

5.4. Vascular Complications

A tourniquet should only be applied after confirming presence of normal blood supply. It is important to palpate the peripheral pulses, assess the capillary filling time and note the state of the skin and nails. Brittle dry nails, shining scaly skin and loss of hairs indicate poor circulation. The presence of varicose veins increases the chances of postoperative deep vein thrombosis and swelling. The application of a tourniquet to a limb with atheromatous vessels commonly the superficial femoral artery, may result in poor wound healing. A tourniquet should never be applied to a limb that has had an arterial prosthesis inserted. The arterial implant is insufficiently elastic to dilate after release of the tourniquet and collateral circulation is likely to be defective. Acute vascular insufficiency following a total knee replacement may be caused either by direct injury to a major vessel or by thrombosis in an intact but diseased vascular system. Rush *et al.* postulated that the pressure of the tourniquet may damage athero-

matous vessels causing fractures of plaques and distal thrombosis [63].

Correction of a flexion deformity can result in a traction injury to the vessels. Stretching of atheromatous vessels may cause initial disruption and subsequent thrombosis. Due to calcification the vessels may be incompressible even when the cuff is inflated to the maximum. Elderly and patients on steroid must be evaluated for vessel calcification [64,65].

5.5. Damage to Skin

Burns occur when the padding under the tourniquet becomes soaked by the antiseptic solution used to paint the skin. Aqueous solutions are not known to cause burns. Antibacterial agents are not responsible for complications except in specific allergic reactions, which are rare. Alcohol-based solutions appear to be the most likely cause. The burns are due to prolonged contact of alcohol-based solutions since evaporation is prevented under the tourniquet. Care must be taken to prevent burns. The skin preparation should be applied well distally to the tourniquet in operations below the knee or elbow. Solutions should not be applied too liberally as this promotes spillage and trickling towards the tourniquet.

5.6. Thrombosis

Deep venous thrombosis and pulmonary embolism are a major cause of morbidity and mortality in lower extremity surgery. Deep venous thrombosis has been identified at autopsy as the source of pulmonary embolism in several cases of tourniquet - related cardiac arrest. Less severe episodes of venous embolism during surgery using tourniquets may not be recognized by simple clinical observation.

6. PRACTICAL TIPS

6.1. Pressure Setting

“Limb occlusion pressure (LOP)” can be defined as the minimum pressure required, at a specific time in a specific tourniquet cuff applied to a specific patient’s limb at a specific location, to stop the flow of arterial blood into the limb distal to the cuff [66].

Basing tourniquet pressure settings on LOP is better than older methods of fixed pressure levels, or based on a patient’s systolic blood pressure. Setting tourniquet pressure to standard levels will generally be too high or too low it is known that high pressure is

associated with a higher probability of nerve injury and other soft tissue injuries, and under-pressurization is associated with the leakage of arterial blood distally and anesthetic agent proximally in Bier block procedures [67]. Setting tourniquet pressure at fixed value above pre-operative systolic blood pressure is inadequate, as it does not take into account adjustments that must be made due to differing cuff widths, cuff shape and limb shape, and amount of tissue below the cuff. Setting tourniquet pressure as a function of LOP inherently takes into account all of these variables.

LOP can be measured in two ways for a specific cuff applied to a specific limb at a specific limb location. Cuff pressure can be increased slowly from zero while monitoring the pulse in an artery distal to the cuff until the distal pulse disappears the lowest cuff pressure at which the pulse disappears can be defined as the ascending LOP. Second, cuff pressure can be decreased slowly (1mmHg/s) from a high occlusive level while monitoring an artery distal to the cuff until a distal pulse resumes the highest pressure at which pulsatile flow first resumes can be defined as the descending LOP. The mean of the ascending and descending LOP can be used as an estimate of the true LOP.

Monitoring of the distal pulse can be done conveniently by palpation, Doppler ultrasound or photoplethysmography (such as a pulse oximeter sensor). Automatic monitoring of the distal pulse and automatic estimation of the LOP by tourniquet instrumentation may save time and improve the consistency of LOP estimates.

The currently established guideline for setting tourniquet pressure based on LOP is as follows:

- 1) For single-bladder tourniquet cuffs of any width applied to upper limb of an adult, tourniquet pressure should be set at LOP + 40 mmHg for LOP levels less than 130 mmHg, LOP + 60 mmHg for LOP levels between 131 - 190 mmHg, and LOP + 80 mmHg for LOP levels greater than 190 mmHg.
- 2) For single-bladder tourniquet cuffs of any width applied to the lower limb of an adult, tourniquet pressure should be set at LOP plus 75 mmHg.
- 3) For dual-bladder (Bier block) tourniquet cuffs of any width and type applied to an adult, LOP should be measured for each bladder and tourniquet pressure should be set at the higher LOP plus 100 mmHg

6.2. Selection of Cuff

Tourniquet cuffs are commonly available in dual port (two tubes per cuff) or single port (one tube per cuff) configurations. Dual port cuffs have two separate tubing connections between the instrument and each attached cuff. One port regulates the pressure in the cuff and the other monitors pressure in the cuff. Dual port instruments and cuffs provide the most accurate and reliable indicator of pressure within the cuff.

Tourniquet instruments are available in single and double channel configurations. Dual channel instruments can control the pressure in two cuffs at once and can be used in bilateral and IVRA (Bier Block) procedures. Each cuff channel should have independent indicator for inflation time and cuff pressure and independent controls for cuff inflation and deflation. The indicators and cuff tubing should be color coded to help identify the cuff connected to each channel. For additional safety systems to help prevent inadvertent cuff deflation during IVRA procedures should be present.

Selecting a cuff that is too long results in excessive overlap and may be difficult to apply snugly and may be less stable causing the cuff to move distally. This may prevent occlusion of arterial blood flow at normal cuff pressures, lead to loss of occlusion and bleeding during the procedure and lead to skin injury. Selecting a cuff that is too short resulting in too little overlap of the inflatable bladder portion of the cuff produces uneven distribution of pressure and can lead to loosening of the cuff or an inability to sustain occlusion. To determine the appropriate cuff length, measure the circumference of the limb near the middle of the part chosen for the cuff and refer to the cuff manufacturer's instructions for the appropriate cuff size. Maximum overlap must be between $\frac{1}{4}$ and $\frac{1}{2}$ of the overall cuff length.

Select a cuff as wide as possible that limb accommodates. It has been shown that a cuff with a wider bladder occludes blood flow at a lower pressure level than narrow bladder. Wider cuff is more efficient at pressure transmission to the deeper tissues. The lower pressure may reduce the risk of pressure related nerve injury. Care must be taken with small adult patients and pediatric patients and ensure that the correct cuff width is used and the cuff edges do not lie close to the joints of the limb to reduce the risk of nerve injury.

Proper application of cuff pressure to the limb requires that the cuff be in close contact across the entire width of the cuff to attain this the cuff shape must

match limb shape. Standard cylindrical tourniquet cuffs are ideally suited for application only to patients with cylindrical limbs. When applied to a contoured or tapered limb the cylindrical cuff will not match the patient's limb shape. This results in snug fit proximally and loose fit distally. This mis-match does not allow even pressure to be applied to the limb from proximal to distal cuff edges. On a contoured limb, a cylindrical cuff may prove unable to achieve a bloodless field distal to the cuff at a "normal" tourniquet pressure and higher tourniquet pressure may be required to achieve a bloodless field, which increases injury risk. Also a cylindrical tourniquet cuff is applied to a contoured or tapered limb has tendency to roll or slide distally during a surgical procedure. This may affect the ability of the cuff to occlude blood flow, and may lead to high pressure gradients at the distal cuff edge, a hazard that may lead to nerve injury. Variable-fit contour cuffs have been introduced which improve tourniquet safety by incorporating structural improvements and a much improved fastening elements. These fasteners incorporate pivoting securing straps, which allow the cuff to adapt and match the shape of limbs of different shapes and sizes, while at the same time allowing the cuff to be secured by dual independent fasteners for improved safety. This design consistently allows the cuff to fit uniformly onto limbs having a wide range of limb contours, tapers and sizes. This close shape match is not possible with cylindrical tourniquet cuffs, nor is it possible with non-variable contour cuffs [68].



Figure 1: Variable fit contoured Cuff.

6.3. Limb Protection Sleeves

When High-pressure gradients and shear forces are applied to skin and soft tissues underlying a tourniquet cuff can cause injuries including petechiae, blistering, bruising, and pinching. To reduce such injuries studies

have been taken up to determine the relative effectiveness of underlying padding, underlying stockinette, and underlying limb protection sleeves that are matched to specific limb sizes and cuff sizes.

Olivecrona *et al.* [69] compared the use of elastic stockinette, cast padding, and no protective material underneath a pneumatic tourniquet in 92 patients undergoing primary total knee arthroplasty and showed that an elastic stockinette provided the most effective skin protection during tourniquet use. McEwen *et al.* [70] compared five different tourniquet cuff sleeve and padding configurations in healthy adult volunteers, and Tredwell *et al.* [71] compared four different tourniquet cuff sleeve and padding configurations on healthy child volunteers. It was found that stretched sleeves made of two-layer tubular elastic material and matched to specific tourniquet cuff sizes produced significantly fewer, less severe pinches and wrinkles in the skin surface than other types of underlying limb protection.



Figure 2: Limb protection sleeves.

6.4. Documenting Tourniquet Use

Documentation of tourniquet use is always a nursing responsibility. Careful records become particularly important if a patient sustains an injury and a lawsuit is filed. It further helps in improving patient care and research. Information is usually entered on a special record. Such records include, at minimum, the following items:

- Identification/serial number and model of the tourniquet.
- Identification of the person who applied the cuff.
- Location of the cuff.
- Times of inflation and deflation of the tourniquet.
- Length of tissue aeration periods, if applicable.

- Original tourniquet pressure.
- Initial systolic blood pressure.
- Subsequent systolic blood pressures.
- The fact that the surgeon was informed of elapsed tourniquet time and any alterations in systolic blood pressure.
- Skin and tissue integrity under the cuff before use of the pneumatic tourniquet and when the patient is sent to postanesthesia recovery.
- Any abnormal or adverse occurrences.

If an untoward event occurs, note the time any symptoms began and ended. Enter adverse reactions on the appropriate record, as dictated by institutional policy. If a malfunction in the pneumatic tourniquet causes serious injury, or contributes to the death of a patient or other individual, this information should be reported to the manufacture and manufacture licensing agencies.

7. CONCLUSION

Tourniquet is invaluable instrument to plastic, hand and orthopedic surgeon. It helps create a bloodless field for easy operation and reduces operative time. The advantages of tourniquet is no without its share of complication including nerve and skin injuries and devastating vascular lesions leading to amputation or death. A thorough understanding of the local and systemic effect of tourniquet is essential to minimize the complication.

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