

Tourniquet in Surgery of the Limbs: A Review of History, Types and Complications

Alireza Saied¹; Alia Ayatollahi Mousavi²; Fateme Arabnejad³; Afshin Ahmadzadeh Heshmati^{4,*}

¹Department of Orthopedics, Kerman Neuroscience Research Center, Kerman University of Medical Sciences, Kerman, IR Iran

²Department of Neuroscience, Kerman Neuroscience Research Center, Kerman University of Medical Sciences, Kerman, IR Iran

³School of Medicine, Kerman University of Medical Sciences, Kerman, IR Iran

⁴Department of Orthopedics, School of Medicine, Kerman University of Medical Sciences, Kerman, IR Iran

*Corresponding Author: Afshin Ahmadzadeh Heshmati, Department of Orthopedics, School of Medicine, Kerman University of Medical Sciences, Kerman, IR Iran. Tel: +98-3412221600, Fax: +98-3412231969, E-mail: Dr.Heshmati@kmu.ac.ir

Received: December 14, 2012; **Revised:** November 4, 2013; **Accepted:** November 12, 2014

Context: A tourniquet is a device that is used frequently in most orthopaedic surgeries but this routine device can lead to serious complications so we decided to review and declare it for safe instruction and use.

Evidence Acquisition: We searched the word "tourniquet" in PubMed and Google and reviewed all full text English articles and abstracts of non-English articles. In addition, we read all the reference pages of articles to find the new references.

Results: The use of tourniquet in orthopedic surgery can lead to serious but rare complications that can be prevented by its correct knowledge and use.

Conclusions: At present, there is not enough evidence to discontinue the routine uses of tourniquets.

Keywords: Tourniquet; Orthopedic Surgeries; Limbs

1. Context

Tourniquet is a device that prevents blood passage in the limbs and makes surgeries much easier. Its usage is universal, but many controversies remain about it and with passage of time some principles have changed. Tourniquet use may be dangerous and in some instances may be contraindicated. In this review article we will have a look at history and usage of this device.

2. Evidence Acquisition

We searched the word "tourniquet" in PubMed and Google and reviewed all full text English articles and abstracts of non-English articles. In addition, we read all the reference pages of articles to find the new references. The search for the word tourniquet resulted in 5254 results in PubMed including 325 reviews and 23 free full text available papers. Finally we reviewed 150 papers that seemed to be of importance for the topic.

2.1. History

The first recorded efforts to prevent arterial bleeding has been ascribed to Sushruta, the father of surgical art and science, in 600 B.C. At that time, 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 use of the tourniquet, which prevents blood entrance and exit from the limb, has been historically close to amputation. The tourniquet was first used in 200 BC and continued up to 500 A.C during Roman emperors' era (2). At that time, saving the life of soldiers or patients with ignorance of the limb was the goal and leather instruments or bronze rings were used for this purpose. Archigenes and Heliodorus who used to practice in Ancient Rome at the time of Celsus used narrow bands of cloth that were placed directly above and below the lines of incision with each passing two or three times around the limb (3). Galen, the most famous surgeon of Rome, advocated against the use of tourniquet because it increased bleeding and probably caused low blood pressure that suppressed the venous return (4). It does not seem that the situation changed over the next 1,500 years. Ambroise Paré, a French surgeon in 16th century, proposed that the upper part of amputation location was knotted by a long string "similar to what women tie onto their hair". The use of a stick to twist the constricting bandage has been ascribed to Hilden (1560 - 1624), Morell (1674), and James Yong (1679) (3). In 1718, Jean-Louis Petit displayed his invention to 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 (4). His invention was a pinned tourniquet formed with a band and a wooden or a tin pin. Lister probably was

the first surgeon who used a blood free field created by a tourniquet in a surgery other than for amputation. In his case of a wrist excision, he declared that the limb must be kept upright for three minutes before using a tourniquet for the blood to exit (5). The next tourniquet that was commonly used was a flat rubber bandage, which was first introduced by Johann Friedrich August von Esmarch, professor of surgery at Kiel University, in 1873. He proposed that the rubber bandage be avoided if the soft tissues contain pus as this was likely to spread the infection (3), which is now accepted as a rule. The next name in this story belongs to Harvey Cushing who invented the pneumatic tourniquet with inspiration from blood barometer after dissatisfaction with the Esmarch band because of its possible neurologic complications (6). Then, this was improved upon by Kirschner. In 1908, August Bier invented a new method to anesthetize the limb by using a tourniquet placed above the site and injecting the anaesthetic into the vein (7). In the next years, tourniquet designs improved and became safer. In 1984 Mac Evan, a biotechnology engineer from Vancouver, invented a micro computerized tourniquet systems (8). These newer systems have the ability to measure pressure and tourniquet time continuously to 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 (2).

2.2. Types

Generally, there are two types of tourniquets: surgery and emergency. Surgical Tourniquets are used in orthopaedic and plastic surgeries for creation of a bloodless field, greater safety, better precision, and more convenience for the surgeon. Another use of the tourniquet is as a regional anaesthetic. Emergency tourniquets are used to control bleeding in accidents or war. The tourniquet also can be of pneumatic (air use) or Esmarch types. Nowadays, most tourniquets are of the pneumatic design. In this paper, we focus mainly on surgical and pneumatic tourniquets.

2.3. Utilization

In some cases the use of the tourniquet is a luxury while in others, the surgery is impossible without it, such as delicate surgeries in the hand. Bunnell statement should be considered: "Hand surgery without tourniquet is like repairing a clock in an ink container" (9). The use of the tourniquet helps to create a bloodless field in surgery, results in better surgeon visualization, and, theoretically, reduces the time of surgery (10). At least one study in knee arthroscopy (11) and one systematic review on upper limb surgery (12) concluded that the tourniquet does not reduce the time of surgery. In the past, it was mentioned that the tourniquet must be wrapped on the uppermost part of the limb, but nowadays use of a forearm (13), leg (14), wrist (15), and ankle (16) tourniquets has gained pop-

ularity. Some studies have reached the conclusion that forearm tourniquets are more endurable in comparison to arm tourniquets. Also, ankle tourniquets are more comfortable than leg tourniquets (14, 17, 18) while some have concluded that in the upper limbs there is no difference between the arm and forearm (19, 20). The skin beneath the tourniquet must be protected by enough layers as a protector. Tourniquet efficacy is reduced with increasing the number of padding layers and it has been suggested that the number should be no more than two (21). The protector can be made of wool, cotton, stocking band, or reconstructed material and there is no difference among them (22). Stocking band maybe somewhat better for the lower limb (23). Care should be taken to keep washing liquid from penetrating beneath the tourniquet at the time of preparation of the limb because it can lead to severe dermal reactions (23) or loss of a partial or full thickness area of the skin (24, 25). This risk is higher in children and the elderly (26) and occurs mostly with alcohol containing solutions (27). To prevent this, a sterile towel, a piece of plastic, a surgical glove, or premade instruments (28) may be used under the tourniquet. To empty the limb of blood, it is kept upright for two minutes or an elastic band is used. One study concluded that the time of up righting doesn't differ in 5, 15, 30, 45 seconds, and 1-4 minutes (29). The methods of limb blood draining have been compared to each other as well with the Esmarch method and blood sucking equal for surgeon convenience in practice and were better than just up righting alone (30). Lower pressure is needed with wider tourniquet cuffs (31). Wide cuffs in association with automatic limb pressure measurement systems have reduced tourniquet pressure by 40% (32). Nowadays, with the appearance of the concept of limb occlusion pressure, any single formula for measuring tourniquet pressure may not be useful. Limb occlusion pressure is the minimum pressure in some special time with a special cuff to a special part of a particular limb that results in the disappearance of limb pulse (33). Advanced tourniquets have instruments for measuring this pressure but a security border must be added to be sure of its efficacy. Still some systems adjust tourniquet pressure according to systolic pressure (34). It has been suggested that in a healthy person less than 50 years old, it is better not to use a tourniquet for more than two hours. Two hours has a logical basis, since after this time of ischemia, progressive venous acidosis will occur in the region the tourniquet effects (35).

2.4. Some Methods Have Been Suggested to Increase the Safe Time of Tourniquet

1) If the operation is predicted to be more than 3 hours long, then breathing time must be considered and after 2 hours, as a routine practice, the tourniquet is released for half an hour (36). However, it takes 40 minutes for the limb to return to the normal metabolic state. One study reached the conclusion that the transient reperfusion

course may not be useful (37).

2) By utilizing double tourniquet cuffs and intermittent discontinuance of one, the safe time of the tourniquet can be prolonged up to 4 hours (38).

3) Coldness reduces the effect of ischemia in tissues, so it is justifiable that cooling the limb is along with an increase in the safe time of the tourniquet, which has been confirmed in animal (39) and human (40) studies but making tissues cold during the surgery is not simple or practical. Considering the role of antibiotics before the surgery to control infections, it seems logical that they should be prescribed before inflating the tourniquet and the time of injection has been mentioned as 20 (41), 5 (42), 2 (43), and 1 (44) minutes before inflation. However, another study concluded that antibiotic prescriptions before inflating the tourniquet do not seem to have any superiority to antibiotic injection after inflation (44). A recent clinical trial compared prophylactic antibiotic use before and after tourniquet inflation in lower limb surgeries. They concluded that in the "before group" the risk of infection and the time of complete healing of the wound had increased and patient satisfaction was lowered (44).

3. Results

3.1. Complications

A famous complication is tourniquet pain that may be the result of mechanical pressure and ischemia reperfusion mechanism (37). Surely the central nervous system may also be involved (45). One study concluded that pain is not related to cuff width and tourniquet pressure (46) but another still says 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 and the efficacy of local 5% lidocaine; and prilocaine cream is the same as subcutaneous injection as well as associated with less patient discomfort (48). Using lidocaine with edible gabapentin (49), ketamine (50), dexamethasone, and ketorolac (51) may lead to more efficient pain reduction. Neural injuries are most often reported in the upper limb but may occur in the lower limb as well. Neural injuries consist of a spectrum from simple paresthesia to permanent paralysis. These are not common. In a large study, their incidence was reported 0.024% and from 15 reported injuries 13 resolved spontaneously after six months (52). Serious injuries may be caused by improper function of the tourniquet gauge (53) and some tourniquets have been found to apply even 500 (54) mmHg more pressure to the limb than what was indicated. The inaccuracy of a tourniquet gauge is not a rare event. On the contrary, it is common. In the above mentioned studies (53, 54), 65% of tourniquet gauges were inaccurate and in another study 35% were inaccurate (55). Some cases of fatal pulmonary emboli have been reported after the Esmarch band for draining the

blood from the limb. Most of them were after trauma (56, 57) but it has been reported after elective surgeries (58). Most arterial injuries occur after a tourniquet is used in knee joint replacement surgery and are the result of indirect injury and thrombosis, especially in the limbs with previous blood flow problems (59). The tourniquet has caused a compartment syndrome in some cases (60-63). Pulmonary embolisms are a rare complication after tourniquet use that may occur before (64) or after (65, 66) deflation. Controversy exists about the role of the tourniquet in causing deep venous thrombosis and pulmonary emboli. Most studies had been about knee arthroplasty. One group believes that this risk does not increase (67) but other studies do not agree (67-70). The mechanism of this injury by tourniquet has been proposed to be venous stasis, endothelial injury, and platelet aggregation (71-73). Tourniquets may increase blood pressure, probably because of autonomous nervous system changes (74) and, especially, in children, it may induce hyperthermia. Pulmonary gas exchange disorder may occur a few hours after tourniquet deflation and in the safe time limit of tourniquet time (75). After deflation pulse and end tidal CO_2 increases to reach a peak after 5 minutes and after 15 minutes returns to the normal range. These are usually benign changes but in patients with cardiovascular or intracranial problems, they may become important. In these cases with hemodynamic and end tidal volume monitoring, quick liquid injection with hyperventilation for 15-30 minutes after deflation is recommended (76). Since tourniquet use leads to ischemia in the limb, though temporarily it is arguable that it can affect the results of surgery for a fracture. One study on tibia fractures treated with plate and screws did not show any harmful effects from tourniquets (77). Another study on the same topic in which statistical analysis was not performed and did not show great differences between the two groups except some skin blisters in the tourniquet group (78). Despite this, the authors recommended against tourniquet use. Another study on fibula fractures concluded that tourniquet use would increase the risk of wound infection (79). A systematic review of the tourniquet in leg and ankle surgery showed that by avoiding tourniquet use, postoperative pain, limb edema, infection, and deep vein thrombosis decreased (80). Actually, with a high probability the postoperative pain would decrease if a tourniquet were not used (77, 81-84). Although, this is not confirmed in all studies (12). Tourniquet use when reaming the canal of the fractured tibia for placing intramedullary nails is absolutely contraindicated (85), since it may lead to severe burning bone necrosis (86, 87), though this has been questioned by at least one study (88). One study concluded that in multiple trauma patients, whose femur fracture was treated by intramedullary nail, tourniquet use for other lower limb fractures might increase pulmonary morbidity (89). Tourniquet use with sickle cell anemia is controversial. Tourniquets cause hemostasis, acidosis, and hypoxia in the tissues dis-

tal to the tourniquet and all these situations are directly related to sickling of blood cells in sickle cell patients. This is not confirmed in practice and a new study reviewing previous studies concluded that by taking precautionary measures and prior readiness, a tourniquet can be used in these patients with proportional safety (90). As authors mention, this topic has not been studied largely and many of the published articles were case reports. Not many studies have been performed on tourniquet use in children (91-93) (to the best of our knowledge). In fact, the principles are not much different from adults. A recent paper repeats adult recommendations (91) that have already been mentioned previously (92). A recent case report referred to the sudden and harmful effects of tourniquet use in two children even with pressures only 50 mmHg higher than patient systolic pressure and emphasized the need for special criteria for children (93). Peripheral vascular diseases in which end limb pulses are not palpable are relative contraindications for tourniquet use. The use of tourniquets in patients who have congenital susceptibility for nerve compression is contraindicated. Use of tourniquets in neuropathies, systemic lupus erythematosus, underlying coagulation disorders, and cachectic patients must be done with caution (94).

4. Conclusions

Tourniquet use in limb surgery is not without risk and though very sophisticated devices have developed, the risk has not been omitted. So its usage would take place with extreme caution. At present there is no evidence for discontinuation of tourniquet use in limb surgeries, but in some instances like children and patients with sickle cell anemia the need for further studies is obvious.

Acknowledgements

The authors declare their gratitude towards the kind personnel of the library of Kerman University of Medical Sciences for their cooperation in data gathering.

Authors' Contributions

Study concept and design: Dr. Saied; Acquisition of data: Dr. Ayatollahi Mousavi, Dr. Arabnejad; Analysis and interpretation of data: Dr. Heshmati, Dr. Saied; Drafting of the manuscript: Dr. Ayatollahi Mousavi, Dr. Arabnejad, Dr. Heshmati; Critical revision of the manuscript for important intellectual content: Dr. Saied; Statistical analysis: Dr. Heshmati, Dr. Saied; Administrative, technical, and material support: Dr. Heshmati, Dr. Saied, Dr. Ayatollahi Mousavi, Dr. Arabnejad; Study supervision: Dr. Saied.

References

- Bhattacharya S, Sushrutha - our proud heritage. *Indian J Plast Surg.* 2009;**42**(2):223-5.
- Klenerman L. The tourniquet in surgery. *J Bone Joint Surg Br.* 1962;**44-B**:937-43.
- Noordin S, McEwen JA, Kragh JF, Jr., Eisen A, Masri BA, . Surgical tourniquets in orthopaedics. *J Bone Joint Surg Am.* 2009;**91**(12):2958-67.
- Desiron Q. History of instrumental haemostasis and the particular contribution of Jules E. Pean. *Acta Chir Belg.* 2007;**107**(1):88-95.
- Fu Kuo-Tai L. Great Names in the History of Orthopaedics XIV: Joseph Lister (1827-1912) Part 1. *J Orthop Trauma Rehabil.* 2010;**14**(2):30-8.
- Cushing H. *Pneumatic tourniquets: with especial reference to their use in craniotomies.*: Medical news; 1904.
- Reis Jr AD. Intravenous regional anesthesia first century (1908-2008): Home, development and current state. *Braz J Anesthesiol.* 2008;**58**(3):299-322.
- McEwen JA. Complications of and improvements in pneumatic tourniquets used in surgery. *Med Instrum.* 1981;**15**(4):253-7.
- Flatt AE. Tourniquet time in hand surgery. *Arch Surg.* 1972;**104**(2):190-2.
- Whitehead DJ, MacDonald SJ. TKA sans tourniquet: let it bleed: opposes. *Orthopedics.* 2011;**34**(9):e497-9.
- Hoogeslag RAG, Brouwer RW, van Raay JJ. The value of tourniquet use for visibility during arthroscopy of the knee: a double-blind, randomized controlled trial. *Arthrosc J Arthroscopy Relat Surg.* 2010;**26**(9):S67-72.
- Smith TO, Hing CB. Should tourniquets be used in upper limb surgery? A systematic review and meta-analysis. *Acta Orthop Belg.* 2009;**75**(3):289-96.
- Swan KG, Jr, Wright DS, Barbagiovanni SS, Swan BC, Swan KG. Tourniquets revisited. *J Trauma.* 2009;**66**(3):672-5.
- Rudkin AK, Rudkin GE, Dracopoulos GC. Acceptability of ankle tourniquet use in midfoot and forefoot surgery: audit of 1000 cases. *Foot Ankle Int.* 2004;**25**(11):788-94.
- Karalezli N, Ogun CO, Ogun TC, Yildirim S, Tuncay I. Wrist tourniquet: the most patient-friendly way of bloodless hand surgery. *J Trauma.* 2007;**62**(3):750-4.
- Derner R, Buckholz J. Surgical hemostasis by pneumatic ankle tourniquet during 3027 podiatric operations. *J Foot Ankle Surg.* 1995;**34**(3):236-46.
- Hutchinson DT, McClinton MA. Upper extremity tourniquet tolerance. *J Hand Surg Am.* 1993;**18**(2):206-10.
- Finsen V, Kasseth AM. Tourniquets in forefoot surgery: less pain when placed at the ankle. *J Bone Joint Surg Br.* 1997;**79**(1):99-101.
- Odinsson A, Finsen V. The position of the tourniquet on the upper limb. *J Bone Joint Surg Br.* 2002;**84**(2):202-4.
- Edwards SA, Harper GD, Giddins GE. Efficacy of forearm versus upper arm tourniquet for local anaesthetic surgery of the hand. *J Hand Surg Br.* 2000;**25**(6):573-4.
- Rajpura A, Somanchi BV, Muir LT. The effect of tourniquet padding on the efficiency of tourniquets of the upper limb. *J Bone Joint Surg Br.* 2007;**89**(4):532-4.
- Din R, Geddes T. Skin protection beneath the tourniquet. A prospective randomized trial. *ANZ J Surg.* 2004;**74**(9):721-2.
- Olivecrona C, Tidermark J, Hamberg P, Ponzer S, Cederfjall C. Skin protection underneath the pneumatic tourniquet during total knee arthroplasty: a randomized controlled trial of 92 patients. *Acta Orthop.* 2006;**77**(3):519-23.
- Madhok R. Chemical burns beneath tourniquets. *Br Med J.* 1989;**298**(6668):254.
- Sarkhel T, Stride V. The TourniquAid: prevention of chemical burns. *Injury.* 2002;**33**(1):73-4.
- Tomlinson PJ, Harries WJ. The use of a surgical glove in the prevention of tourniquet-associated chemical burns. *Ann R Coll Surg Engl.* 2008;**90**(3):255.
- Nahlieli O, Baruchin AM, Levi D, Shapira Y, Yoffe B. Povidone-iodine related burns. *Burns.* 2001;**27**(2):185-8.
- Bayne D. Prevention of chemical burns. *Ann R Coll Surg Engl.* 2008;**90**(8):715.
- Blond L, Madsen JL. Exsanguination of the upper limb in healthy young volunteers. *J Bone Joint Surg Br.* 2002;**84**(4):489-91.
- Blond L, Jensen NV, Soe Nielsen NH. Clinical consequences of different exsanguination methods in hand surgery: a double-blind randomised study. *J Hand Surg Eur Vol.* 2008;**33**(4):475-7.
- Moore MR, Garfin SR, Hargens AR. Wide tourniquets eliminate blood flow at low inflation pressures. *J Hand Surg Am.* 1987;**12**(6):1006-11.

32. Younger AS, McEwen JA, Inkpen K. Wide contoured thigh cuffs and automated limb occlusion measurement allow lower tourniquet pressures. *Clin Orthop Relat Res.* 2004;**428**:286-93.
33. Oragui E, Parsons A, White T, Longo UG, Khan WS. Tourniquet use in upper limb surgery. *Hand (NY).* 2011;**6**(2):165-73.
34. Ishii Y, Noguchi H, Matsuda Y, Takeda M, Higashihara T. A new tourniquet system that determines pressures in synchrony with systolic blood pressure in total knee arthroplasty. *J Arthroplasty.* 2008;**23**(7):1050-6.
35. Wilgis ES. Observations on the effects of tourniquet ischemia. *J Bone Joint Surg.* 1971;**53**(7):1343-6.
36. Beekley AC, Sebesta JA, Blackburne LH, Herbert GS, Kauvar DS, Baer DG, et al. Prehospital tourniquet use in Operation Iraqi Freedom: effect on hemorrhage control and outcomes. *J Trauma.* 2008;**64**(2 Suppl):S28-37.
37. Estebe JP, Malledant Y. [Pneumatic tourniquets in orthopedics]. *Ann Fr Anesth Reanim.* 1996;**15**(2):162-78.
38. Dreyfuss UY, Smith RJ. Sensory changes with prolonged double-cuff tourniquet time in hand surgery. *J Hand Surg Am.* 1988;**13**(5):736-40.
39. Fish JS, McKee NH, Kuzon WM, Jr., Plyley MJ. The effect of hypothermia on changes in isometric contractile function in skeletal muscle after tourniquet ischemia. *J Hand Surg Am.* 1993;**18**(2):210-7.
40. Swanson AB, Livengood LC, Sattel AB. Local hypothermia to prolong safe tourniquet time. *Clin Orthop Relat Res.* 1991;**264**:200-8.
41. Papaioannou N, Kalivas L, Kalavritinos J, Tsourvakas S. Tissue concentrations of third-generation cephalosporins (ceftazidime and ceftriaxone) in lower extremity tissues using a tourniquet. *Arch Orthop Trauma Surg.* 1994;**113**(3):167-9.
42. Friedman RJ, Friedrich LV, White RL, Kays MB, Brundage DM, Graham J. Antibiotic prophylaxis and tourniquet inflation in total knee arthroplasty. *Clin Orthop Relat Res.* 1990;**260**:17-23.
43. Bannister GC, Auchincloss JM, Johnson DP, Newman JH. The timing of tourniquet application in relation to prophylactic antibiotic administration. *J Bone Joint Surg Br.* 1988;**70**(2):322-4.
44. Akinyoola AL, Adegbehingbe OO, Odunsi A. Timing of antibiotic prophylaxis in tourniquet surgery. *J Foot Ankle Surg.* 2011;**50**(4):374-6.
45. Estebe JP, Kerebel C, Brice C, Lenaoures A. [Pain and tourniquet in orthopedic surgery]. *Cah Anesthesiol.* 1995;**43**(6):573-8.
46. Crews JC, Hilgenhurst G, Leavitt B, Denson DD, Bridenbaugh PO, Stuebing RC. Tourniquet pain: the response to the maintenance of tourniquet inflation on the upper extremity of volunteers. *Reg Anesth.* 1991;**16**(6):314-7.
47. Hagenouw RR, Bridenbaugh PO, van Egmond J, Stuebing R. Tourniquet pain: a volunteer study. *Anesth Analg.* 1986;**65**(11):1175-80.
48. Inal S, Er M, Ozsoy M, Cavusoglu A, Dincel V, Sakaogullari A. Comparison of two different anesthesia techniques for tourniquet pain with the use of forearm tourniquet. *Iowa Orthop J.* 2009;**29**:55-9.
49. Turan A, White PF, Karamanlioglu B, Pamukcu Z. Premedication with gabapentin: the effect on tourniquet pain and quality of intravenous regional anesthesia. *Anesth Analg.* 2007;**104**(1):97-101.
50. Arslan M, Canturk M, Ornek D, Gamli M, Pala Y, Dikmen B, et al. Regional intravenous anesthesia in knee arthroscopy. *Clinics (Sao Paulo).* 2010;**65**(9):831-5.
51. Jankovic RJ, Visnjic MM, Milic DJ, Stojanovic MP, Djordjevic DR, Pavlovic MS. Does the addition of ketorolac and dexamethasone to lidocaine intravenous regional anesthesia improve postoperative analgesia and tourniquet tolerance for ambulatory hand surgery? *Minerva Anestesiol.* 2008;**74**(10):521-7.
52. Odinson A, Finsen V. Tourniquet use and its complications in Norway. *J Bone Joint Surg Br.* 2006;**88**(8):1090-2.
53. Irwing GA, Christopher K. Inaccurate tourniquet pressure-gauge readings—a widespread problem. *S Afr Med J.* 1984;**66**(7):265-6.
54. Fry D. Inaccurate tourniquet gauges. *Br Med J.* 1972;**1**(5798):511.
55. Hallett J. Inaccuracies in measuring tourniquet pressures. *Br Med J (Clin Res Ed).* 1983;**286**(6373):1267-8.
56. Pollard BJ, Lovelock HA, Jones RM. Fatal pulmonary embolism secondary to limb exsanguination. *Anesthesiology.* 1983;**58**(4):373-4.
57. Samaan HA. Pulmonary embolism under general anaesthesia, following Esmarch bandage in injuries of lower limb. *Anaesthesia.* 1970;**25**(3):445.
58. Darmanis S, Papanikolaou A, Pavlakis D. Fatal intra-operative pulmonary embolism following application of an Esmarch bandage. *Injury.* 2002;**33**(9):761-4.
59. Smith DE, McGraw RW, Taylor DC, Masri BA. Arterial complications and total knee arthroplasty. *J Am Acad Orthop Surg.* 2001;**9**(4):253-7.
60. O'Neil D, Sheppard JE. Transient compartment syndrome of the forearm resulting from venous congestion from a tourniquet. *J Hand Surg Am.* 1989;**14**(5):894-6.
61. Luk KD, Pun WK. Unrecognised compartment syndrome in a patient with tourniquet palsy. *J Bone Joint Surg Br.* 1987;**69**(1):97-9.
62. Greene TL, Louis DS. Compartment syndrome of the arm—a complication of the pneumatic tourniquet. A case report. *J Bone Joint Surg Am.* 1983;**65**(2):270-3.
63. Moore MR, Garfin SR, Hargens AR. Compartment syndrome of the thigh complicating surgical treatment of ipsilateral femur and ankle fractures. *J Orthop Trauma.* 1987;**1**(1):71-3.
64. Berman AT, Parmet JL, Harding SP, Israelite CL, Chandrasekaran K, Horrow JC, et al. Emboli observed with use of transesophageal echocardiography immediately after tourniquet release during total knee arthroplasty with cement. *J Bone Joint Surg Am.* 1998;**80**(3):389-96.
65. McGrath BJ, Hsia J, Epstein B. Massive pulmonary embolism following tourniquet deflation. *Anesthesiology.* 1991;**74**(3):618-20.
66. Fukuda A, Hasegawa M, Kato K, Shi D, Sudo A, Uchida A. Effect of tourniquet application on deep vein thrombosis after total knee arthroplasty. *Arch Orthop Trauma Surg.* 2007;**127**(8):671-5.
67. Nishiguchi M, Takamura N, Abe Y, Kono M, Shindo H, Aoyagi K. Pilot study on the use of tourniquet: a risk factor for pulmonary thromboembolism after total knee arthroplasty? *Thromb Res.* 2005;**115**(4):271-6.
68. Parmet JL, Horrow JC, Berman AT, Miller F, Pharo G, Collins L. The incidence of large venous emboli during total knee arthroplasty without pneumatic tourniquet use. *Anesth Analg.* 1998;**87**(2):439-44.
69. Kato N, Nakanishi K, Yoshino S, Ogawa R. Abnormal echogenic findings detected by transesophageal echocardiography and cardiorespiratory impairment during total knee arthroplasty with tourniquet. *Anesthesiology.* 2002;**97**(5):1123-8.
70. Shemshaki H, Tehranfar Laripour A, Saadati H, Jalalian M. Effects of Pneumatic Tourniquet on Knee Surgery.
71. Parmet JL, Horrow JC, Singer R, Berman AT, Rosenberg H. Echogenic emboli upon tourniquet release during total knee arthroplasty: pulmonary hemodynamic changes and embolic composition. *Anesth Analg.* 1994;**79**(5):940-5.
72. DeLee JC, Rockwood CA, Jr. Current concepts review. The use of aspirin in thromboembolic disease. *J Bone Joint Surg Am.* 1980;**62**(1):149-52.
73. Francis CW, Pellegrini VD, Jr., Stulberg BN, Miller ML, Totterman S, Marder VJ. Prevention of venous thrombosis after total knee arthroplasty. Comparison of antithrombin III and low-dose heparin with dextran. *J Bone Joint Surg Am.* 1990;**72**(7):976-82.
74. Tetzlaff JE, O'Hara J, Jr., Yoon HJ, Schubert A. Tourniquet-induced hypertension correlates with autonomic nervous system changes detected by power spectral heart rate analysis. *J Clin Anesth.* 1997;**9**(2):138-42.
75. Lin L, Wang L, Bai Y, Zheng L, Zhao X, Xiong X, et al. Pulmonary gas exchange impairment following tourniquet deflation: a prospective, single-blind clinical trial. *Orthopedics.* 2010;**33**(6):395.
76. Zaman SM, Islam MM, Chowdhury KK, Rickta D, Ireen ST, Choudhury MR, et al. Haemodynamic and end tidal CO2 changes state after inflation and deflation of pneumatic tourniquet on extremities. *Mymensingh Med J.* 2010;**19**(4):524-8.
77. Saied A, Zyaei A. Tourniquet use during plating of acute extra-articular tibial fractures: effects on final results of the operation. *J Trauma.* 2010;**69**(6):E94-7.
78. Salam AA, Eyres KS, Cleary J, el-Sayed HH. The use of a tourniquet when plating tibial fractures. *J Bone Joint Surg Br.* 1991;**73**(1):86-7.
79. Maffulli N, Testa V, Capasso G. Use of a tourniquet in the internal fixation of fractures of the distal part of the fibula. A prospective, randomized trial. *J Bone Joint Surg Am.* 1993;**75**(5):700-3.
80. Smith TO, Hing CB. The efficacy of the tourniquet in foot and

- ankle surgery? A systematic review and meta-analysis. *Foot Ankle Surg.* 2010;**16**(1):3-8.
81. Konrad G, Markmiller M, Lenich A, Mayr E, Ruter A. Tourniquets may increase postoperative swelling and pain after internal fixation of ankle fractures. *Clin Orthop Relat Res.* 2005(433):189-94.
 82. Omeroglu H, Gunel U, Bicimoglu A, Tabak AY, Ucaner A, Guney O. The relationship between the use of tourniquet and the intensity of postoperative pain in surgically treated malleolar fractures. *Foot Ankle Int.* 1997;**18**(12):798-802.
 83. Omeroglu H, Ucaner A, Tabak AY, Guney O, Bicimoglu A, Gunel U. The effect of using a tourniquet on the intensity of postoperative pain in forearm fractures. A randomized study in 32 surgically treated patients. *Int Orthop.* 1998;**22**(6):369-73.
 84. Abdel-Salam A, Eyres KS. Effects of tourniquet during total knee arthroplasty. A prospective randomised study. *J Bone Joint Surg Br.* 1995;**77**(2):250-3.
 85. P. WA. . Fractures of the lower extremity. In: S.T. C editor. *Campbell's operative orthopaedics.* 11th ed. Mosby; 2008. pp. 3086-216.
 86. Saldua NS, Kuhn KM, Mazurek MT. Thermal necrosis complicating reamed intramedullary nailing of a closed tibial diaphysis fracture: a case report. *J Orthop Trauma.* 2008;**22**(10):737-41.
 87. Leunig M, Hertel R. Thermal necrosis after tibial reaming for intramedullary nail fixation. A report of three cases. *J Bone Joint Surg Br.* 1996;**78**(4):584-7.
 88. Giannoudis PV, Snowden S, Matthews SJ, Smye SW, Smith RM. Friction burns within the tibia during reaming. Are they affected by the use of a tourniquet? *J Bone Joint Surg Br.* 2002;**84**(4):492-6.
 89. Pollak AN, Battistella F, Pettey J, Olson SA, Chapman MW. Reamed femoral nailing in patients with multiple injuries. Adverse effects of tourniquet use. *Clin Orthop Relat Res.* 1997(339):41-6.
 90. Fisher B, Roberts CS. Tourniquet use and sickle cell hemoglobinopathy: how should we proceed? *South Med J.* 2010;**103**(11):1156-60.
 91. Tredwell SJ, Wilmink M, Inkpen K, McEwen JA. Pediatric tourniquets: analysis of cuff and limb interface, current practice, and guidelines for use. *J Pediatr Orthop.* 2001;**21**(5):671-6.
 92. Reilly CW, McEwen JA, Leveille L, Perdios A, Mulpuri K. Minimizing tourniquet pressure in pediatric anterior cruciate ligament reconstructive surgery: a blinded, prospective randomized controlled trial. *J Pediatr Orthop.* 2009;**29**(3):275-80.
 93. Misra A, Panda A, Sharma R. Tourniquet cuff pressures in pediatric patients: urgent need to device guidelines? *Paediatr Anaesth.* 2010;**20**(4):369-70.
 94. Landi A, Saracino A, Pinelli M, Caserta G, Facchini MC. Tourniquet paralysis in microsurgery. *Ann Acad Med Singapore.* 1995;**24**(4 Suppl):89-93.