Int J Clin Exp Med 2023;16(12):294-300
www.ijcem.com /ISSN:1940-5901/IJCEM0151901

Original Article

Analysis of curative effect of a low position tourniquet in calcaneal fracture surgery

Ying Yao[1*], Yue Zhang[1*], Lu-Yi Zhou[1], Ting-Ting Shi[1], Li-Yu Zhou[1], Jian Fan[2], Guang-Rong Yu[2], Fang-Lei Xu[1]

[1]Department of Nursing, Tongji Hospital, Tongji University, Shanghai 200065, China; [2]Department of Orthopedics, Tongji Hospital, Tongji University, Shanghai 200065, China. [*]Equal contributors.

Received June 25, 2023; Accepted October 31, 2023; Epub December 15, 2023; Published December 30, 2023

Abstract: Objective: This study aimed to investigate the role and effectiveness of using a low-position tourniquet in surgery for calcaneal fractures. Method: A retrospective analysis was conducted on 42 calcaneal fracture patients who underwent reduction and internal fixation with a plate via an L-shaped approach with low-position tourniquets between January 2018 and July 2020. All fractures were fresh, unilateral, and classified as Sanders III and IV. The patients, with an average age of 47.2 years, had no medical complications. The two groups were categorized based on the position of tourniquets during surgery. In one group, the tourniquets were placed on the proximal thighs (high-position tourniquet group, n=22), and in the other group, the tourniquets were positioned above the ankles (low-position tourniquet group, n=20). The following observations were made: operation time, tourniquet time, intraoperative bleeding and incision healing, postoperative fracture healing, ankle-hindfoot scoring system (AOFAS score) and visual analogue scale (VAS score), tourniquet complications such as soft tissue injury and deep venous thrombosis (DVT). Result: No significant differences in general condition, fracture type, and complications of the two groups before surgery were noted (P>0.05). Significantly less foot pain within two weeks after surgery and higher AOFAS scores for motion pain within four weeks after surgery were observed in the low-position tourniquet group compared to the high-position tourniquet group (P<0.05). However, there was no significant difference in AOFAS function scores twelve weeks after surgery between the two groups (P>0.05). Additionally, one case of DVT and two cases of soft tissue injuries were identified in the high-position tourniquet group, while no related complications were encountered in the low-position tourniquet group (P<0.05). Conclusion: The use of a low-position tourniquet in calcaneal fracture surgery ensures clear visibility during the procedure, reduces the incidence of early postoperative pain and related complications, and promotes functional rehabilitation. This new method is considered worthy of recommendation.

Keywords: Low position tourniquet, ankle fracture, curative effect analysis

Introduction

Calcaneal fractures due to trauma are frequently encountered in clinical orthopedics. For the surgical management of Sanders III and IV calcaneal fractures, the lateral L-shaped approach is commonly employed [1]. In the realm of traumatic orthopedics, the adoption of Enhanced Recovery After Surgery (ERAS) protocols has led to pain-free mobility and early rehabilitation. Achieving a reduction in complications and establishing conditions conducive to early functional recovery involves various factors, including preoperative preparations, surgical techniques, and anesthesia. Within these factors, the use of intraoperative tourniquets is pivotal. Currently, the conventional approach involves placing the tourniquet on the proximal thigh, facilitating a clear surgical field for smooth operation. However, this method has been associated with increased postoperative pain, a higher risk of deep vein thrombosis (DVT), and soft tissue injuries over the years, consequently affecting overall treatment efficacy [2-4]. The heightened incidence of complications is primarily attributed to the temporary ischemia induced by the relatively high pressure exerted by the high-position tourniquet on extensive tissues [5].

Recent advancements in tourniquet technology, such as the introduction of timing controls,

Table 1. Comparison of preoperative general data between two groups

Variable	Low position tourniquet (n=20)	High position tourniquet (n=22)	Statistic	*P* value
Gender (male/female)	12/8	13/9	0.089	0.641
Mean age (year)	48.6±8.7	45.2±9.1	1.023	0.142
Time from injury to operation (d, x±s)	6.2±1.2	8.7±1.8	-0.576	0.595
Type of fracture	20	22	1.549	0.508
Sanders III	12	13		
Sanders IV	8	9		
Multiple injuries	Multiple rib fracture (1) Craniocerebral trauma (1)	Craniocerebral trauma (2)	0	0.986

ultrasonic guidance, and intelligent systems, have significantly reduced the occurrence of associated complications. Nonetheless, the issue of soft tissue injuries and DVT persists [6-8]. The substantial pressure applied by thigh tourniquets during surgery leads to temporary ischemia in bone tissue, a major factor contributing to these complications. As a result, we have explored an innovative approach involving low-position tourniquets, which could effectively mitigate tissue ischemia-related damage and theoretically reduce these complications. This study aims to investigate the impact of low-position tourniquets in open reduction and internal fixation compared to high-position tourniquets, with the goal of confirming whether they offer advantages in ensuring a clear surgical field and reducing associated complications.

Methods

Study population

The current study involved the inclusion of a total of 42 patients at Shanghai Tongji Hospital between May 2018 and December 2020. The age range encompassed 19 to 62 years, with an average age of 47.2 years. Injuries were caused by traffic accidents in 25 cases, falls in 9 cases, and walking sprains in 8 cases. The time interval from injury to operation spanned 6 to 12 days, with an average of 7.8 days. Inclusion criteria were as follows: (1) fresh unilateral closed fractures, (2) the absence of soft tissue damage around the ankle and foot, (3) no history of ankle and foot trauma surgery, and (4) well-controlled preoperative basic diseases. Exclusion criteria included: (1) patients with mental disorders, (2) patients with uncontrollable essential hypertension, arrhythmia, or diabetes, and (3) patients with arteriosclerotic occlusive disease, lumbar disc herniation, and other diseases that might affect blood supply, sensation, and lower limb movement. The 42 patients were divided into two groups based on the positioning of the tourniquets during surgery: the low-position tourniquet group (n=20) composed of 12 males and 8 females aged between 21 and 58 years, including 12 cases of Sanders type III fractures and 8 cases of Sanders type IV fractures; and the high-position tourniquet group (n=22) comprising 13 males and 9 females aged between 19 and 62 years, including 13 cases of Sanders type III fractures and 9 cases of Sanders type IV fractures. No skin or soft tissue injuries, nor neurovascular injuries, were detected in either group. There were no statistically significant differences between the two groups in terms of age, time since injury, fracture type, or multiple injuries (**Table 1**).

Surgical methods

Low position tourniquet group: Patients were placed in a side-lying position, and standard draping was carried out after routine disinfection. Sterile tourniquets, approximately 10 cm wide, were applied around the ankle joint, positioned 10 cm above it, with 2-3 layers of gauze placed beneath the tourniquets (**Figure 1**). After blood evacuation, the tourniquet pressure was increased by 30% relative to the patient's systolic blood pressure [4]. An incision in the shape of a modified "L" (8-12 cm in length) was created on the lateral side of the calcaneus. The tissue was dissected layer by layer, with the sural nerve and small saphenous vein being carefully protected. A peroneus longus approach was employed for the lateral malleolus. After precise fracture reduction, the lateral

Figure 1. A 49-year-old man with a traffic injury to his right ankle and foot resulting in a right calcaneal fracture. A, B. Intraoperative tourniquet application. C. Intraoperative surgical field (white arrow).

plate was fixed. Access to the space between the peroneus brevis longus and the flexor pollicis longus was obtained for the posterior malleolus. The Volkmann fracture was exposed and reduced, with the insertion of a screw or buttress plate. A curved incision was selected for the medial malleolus. Following reduction, two hollow screw-type devices or a buttress plate were inserted. In cases of injury to the flexible medial malleolus, the deltoid ligament was explored and repaired.

High position tourniquet group: Automatic pneumatic tourniquets (AST type) were affixed to the proximal thigh with a pressure 100 mmHg higher than the patient's systolic blood pressure. The surgical procedure was identical to that of the low tourniquet group.

Postoperative treatment

Patient-controlled analgesia (PCA) was employed to all patients post-surgery, eliminating the need for additional analgesics. Prophylactic antibiotics were administered as a routine practice within 24-48 hours after the operation. The drainage tube was removed after 24 hours, with the volume of drainage duly recorded. On the second day post-surgery, ankle flexion and extension exercises were initiated, gradually increasing the range based on individual pain tolerance. Color-doppler ultrasounds of the lower limbs were performed to detect potential deep vein thrombosis (DVT) between the 3rd and 7th days post-operation. Passive and active activities, encompassing forward flexion, extension, adduction, and valgus movements, commenced two weeks post-operation. Active exercise training was incrementally intensified, guided by X-ray findings and internal fixation status after one month.

Postoperative follow-up and observation indicators

Operation time, tourniquet time and bleeding volume: Operation time (including tourniquet time) was documented. Evaluation was performed regarding any significant bleeding in the operative area and its impact on the procedure. Intraoperative bleeding volume was calculated by weighing gauze before and after blood absorption. Postoperative bleeding volume was determined by recording the blood collected by the gauze and drainage.

Fracture healing, ankle range of motion and clinical function scores: X-rays or CT scans were conducted at the 4-week, 12-week, 6-month, and 12-month intervals following the operation to assess fracture healing. Measurements were taken for ankle range of motion and function scores. Function was assessed using the American Orthopaedic Foot and Ankle Score (AOFAS). The AOFAS score, which utilizes a 0-100 scale, integrates five patient-reported parameters relating to pain and function with four physician-assessed criteria concerning function and alignment.

Pain and complications: The Visual Analog Scale (VAS), a validated subjective measure for both acute and chronic pain, was employed. Scores were recorded by marking a 10-cm line, representing a continuum from "no pain" to "worst pain". VAS scores (ranging from 0 to 10) were utilized to assess pain in the affected limb within the initial two weeks post-surgery. Color-doppler ultrasounds of the lower limbs were conducted within one-week post-surgery to investigate the occurrence of DVT. Ecchymosis, soft tissue masses, blisters, and skin ulcers at the tourniquet compression site were observed

Table 2. Comparison of operation time, tourniquet time, and blood loss between two groups

Variable	Low position tourniquet (n=20)	High position tourniquet (n=22)	Statistic	*P* value
Operation time (min, x±s)	57.2±14.5	54.6±16.5	-0.679	0.379
Tourniquet time (min, x±s)	50.2±14.5	47.6±16.5	0.734	0.292
Intraoperative bleeding (g)	52.3±9.0	59.3±7.0	0.376	0.718
Postoperative bleeding (g)	102.5±15.2	106.9±19.4	0.205	0.714
Total bleeding (g)	102.5±15.2	106.9±19.4	0.205	0.714

Table 3. Comparison of hind foot mobility and AOFAS scores four weeks after operation between two groups

Variable	Low position tourniquet (n=20)	High position tourniquet (n=22)	Statistic	*P* value
Fracture healing time (W, x±s)	10.2±3.1	11.4±4.3	0.895	0.316
Ankle flexion (degree)	34.2±9.0	31.1±8.5	2.431	0.011*
Ankle dorsiflexion (degree)	30.4±7.2	27.4±6.7	2.253	0.037*
Motion of ankle (degree)	61.0±15.3	48.1±20.2	2.407	0.029*
AOFAS scores	72.1±11.8	64.26±15.9	2.576	0.016*

*P<0.05.

and recorded on the 1st and 7th days post-operation.

Statistical analysis

The normal distribution of data was assessed using the Kolmogorov-Smirnov test. Measurement data conforming to a normal distribution were expressed as means ± standard deviations and compared between groups using two-tailed independent sample t-test. The frequency of nominal variables between groups was determined using the chi-square test and Fisher's exact test. Statistical analysis was conducted using SPSS 13.0 software, and significance was considered when P<0.05.

Results

Operative conditions and fracture healing

The follow-up period for all patients ranged from 4 to 22 months, with an average of 12.6 months. There were no significant differences in operation duration, blood loss, and time required for fracture healing between the two groups (**Table 2**).

Clinical outcome

At four weeks postoperatively, the low-position tourniquet group exhibited higher ankle flexion (34.2±9.0) compared to the high-position tourniquet group (31.1±8.5). Furthermore, the low-position tourniquet group demonstrated greater ankle dorsiflexion (30.4±7.2) than the high-position tourniquet group (27.4±6.7). The range of motion in the ankle joint was significantly greater in the low-position tourniquet group (61.0±15.3) compared to the high-position tourniquet group (48.1±20.2). Moreover, the low-position tourniquet group (72.1±11.8) exhibited higher motion in the ankle than the high-position tourniquet group (64.26±15.9) (**Table 3**). However, there was no significant difference in AOFAS scores twelve weeks post-operation (**Table 4**). Although there was no significant difference in limb pain before the operation between the two groups, VAS scores for the low-position tourniquet group (2.4±0.8) were significantly lower than those for the high-position tourniquet group (3.1±1.1) within two weeks after surgery (**Table 5**).

Complications

In the high-position tourniquet group, one case of DVT and two cases of soft tissue injuries occurred in the thigh binding area. In contrast, no related complications were observed in the low-position tourniquet group (**Table 6**). A representative case is depicted in **Figure 1**.

Discussion and conclusion

The calcaneus, as one of the tarsal bones, constitutes a portion of the hindfoot. Despite its infrequent occurrence, calcaneal fractures rep-

Table 4. Comparison of hind foot mobility and AOFAS scores twelve weeks after operation between two groups

Variable	Low position tourniquet (n=20)	High position tourniquet (n=22)	Statistic	*P* value
Ankle flexion (degree)	37.0±8.1	34.5±6.5	0.261	0.751
Ankle dorsiflexion (degree)	38.2±4.6	37.6±5.7	1.845	0.177
Motion of ankle (degree)	72.6±1.9	71.6±8.1	0.825	0.379
AOFAS scores	87.4±1.9	85.8±2.4	1.710	0.124

Table 5. Comparison of postoperative limb pain (VAS Scores) between two groups

Variable	Low position tourniquet (n=20)	High position tourniquet (n=22)	Statistic	*P* value
Pre-operation	6.4±2.1	7.2±1.9	-0.675	0.486
1 day after operation	5.1±2.2	5.0±1.9	0.145	0.872
3 days after operation	4.8±2.0	4.5±2.1	-0.208	0.731
7 days after operation	2.8±1.4	3.1±1.2	-1.421	0.221
14 days after operation	2.4±0.8	3.1±1.1	-2.191	0.026*

*P<0.05.

Table 6. Comparison of tourniquet-related complications between two groups

Variable	Low position tourniquet (n=20)	High position tourniquet (n=22)	Statistic	*P* value
Skin ecchymosis	0	1	1.023	0.312
Soft tissue mass	0	1	1.023	0.312
Skin blisters	0	0	/	/
Skin ulcer	0	0	/	/
DVT	0	1	1.023	0.312
Total	0	3	3.220	0.073

resent the majority of tarsal fractures. Successful surgical treatment and the mitigation of postoperative pain and complications are undeniably crucial components of ERAS. Presently, proximal thigh tourniquets are widely utilized in calcaneal fracture surgery to ensure optimal visibility during the procedure and enhance surgical comfort. Simultaneously, the utilization of these tourniquets results in a substantial reduction in the incidence of damage to small vessels and nerves, such as the small saphenous vein and the sural nerve. However, associated complications hinder postoperative rehabilitation, including exacerbated postoperative pain, an increased risk of DVT, and soft tissue injuries [9].

Unique characters of Low position tourniquet

Low-position tourniquets are positioned approximately 10 cm above the ankle, where the inflation pressure required for tourniquet application is significantly reduced due to the limited soft tissue and superficial blood vessels. Consequently, the ischemic area induced by low-position tourniquets is substantially reduced, effectively minimizing the risk of ischemia-reperfusion injuries. Furthermore, low-position tourniquets are personally applied to the thigh, thereby reducing the interval between tourniquet activation and the commencement of surgery.

In this study, no significant differences were observed in surgical field quality, operation duration, bleeding volume, or time required for fracture healing between the two groups. While there was no overall difference in AOFAS scores, the scores of the low-position tourniquet group exceeded those of the high-position tourniquet group within the initial 4 weeks post-surgery, indicating the former's advantages. Additionally, VAS scores for the low-position tourniquet group were significantly lower than those for the high-position tourniquet group within the first two weeks following surgery, underscoring the benefits of employing low-position tourniquets in facilitating ERAS. A similar study investigating the use of tourniquets in knee joint replacement surgery found that it promoted early rehabilitation of knee joint function [10]. Regarding complications, although any tourniquet may theoretically entail risks, the related complications in the traditional high-position tourniquet group were notably higher than those in the low-position tourniquet group in this study.

Analysis of superiority of the low position tourniquet group

Conventional low-position tourniquets can lead to venous stasis and ischemia by exerting pressure on local tissues [11-13]. This elevates the risk of venous thromboembolism, neurovascular damage, and wound complications such as infections [4, 14-16]. Additionally, low-position tourniquets have been associated with the induction of pain during and after surgery, necessitating deeper levels of anesthesia and higher doses of analgesics [17]. High levels of post-operative pain can impede early rehabilitation efforts and prolong hospital stays [18].

This study adopted a novel approach aimed at minimizing the adverse effects of tourniquets on normal tissues, departing from traditional thinking. The comprehensive analysis of VAS scores yielded the following insights. Firstly, tourniquet pressure and tissue ischemia were significantly reduced, thereby minimizing compression on the skin, quadriceps, sciatic nerve, and muscle necrosis. Secondly, the levels of hypoxic harmful substances and myoglobin in the blood were effectively reduced, mitigating the risk of ischemia-reperfusion injury [19].

The low-position tourniquet group exhibited superior ankle motion and AOFAS scores compared to the high-position tourniquet group four weeks after surgery. Postoperative pain in the affected limb was alleviated, enabling patients to engage in early passive or active functional exercises. This created favorable conditions for early functional recovery and ERAS, consequently enhancing early ankle range of motion and functional scores.

Regarding soft tissue complications, the low-position tourniquet group did not experience skin congestion or caking. Moreover, there were fewer muscles in the region where the tourniquet was applied at the lower position. The superficial placement of the anterior tibial artery and vein significantly reduced tourniquet inflation pressure, thereby effectively minimizing tissue damage. Additionally, most cases of DVT occur in the long tubular veins of the lower limbs, rather than the short veins located farther from the ankle. Consequently, the low-position tourniquet did not directly affect the proximal part. The lower tourniquet pressure reduced vascular damage, which also played a pivotal role in decreasing the incidence of DVT.

Precautions and prospects

In conclusion, the utilization of tourniquets, whether in a low or high position, satisfies the surgical field requirements in ankle fracture surgery, enabling clinicians to perform operations smoothly under safe conditions. Although the low-position tourniquet may offer superior performance, most clinicians still opt for high-position tourniquets in current clinical practice. This preference is primarily attributed to the convenience of high-position tourniquet application and a lack of focus on minimizing complications among clinicians. It is conceivable that as the concept of ERAS continues to gain traction and societal expectations increase, the adoption of low-position tourniquets may become more widespread. However, our choice of tourniquet pressure settings at 1.5 times systolic pressure and a maximum holding time of 1.5 hours is based on limited existing literature in this field. Additionally, small sample sizes and short-term follow-up periods constrain the scope of this research. Further studies are warranted to explore tourniquet use more comprehensively in the future.

Disclosure of conflict of interest

None.

Address correspondence to: Guang-Rong Yu, Department of Orthopedics, Tongji Hospital, Tongji University, No. 389 Xincun Road, Putuo District, Shanghai 200065, China. E-mail: yuguangrong@tongji.edu.cn; Fang-Lei Xu, Department of Nursing, Tongji Hospital, Tongji University, No. 389 Xincun Road, Putuo District, Shanghai 200065, China. E-mail: 13501792610@163.com

References

[1] Liu XM, Huang M and Wang GD. Application of enhanced recovery after surgery in limb fractures. Journal of Traumatic Surgery 2020; 22: 881-884.

[2] Kruse H, Christensen KP, Møller AM and Gögenur I. Tourniquet use during ankle surgery leads to increased postoperative opioid use. J Clin Anesth 2015; 27: 380-384.
[3] Kumar N, Yadav C, Singh S, Kumar A, Vaithlingam A and Yadav S. Evaluation of pain in bilateral total knee replacement with and without tourniquet; a prospective randomized control trial. J Clin Orthop Trauma 2015; 6: 85-88.
[4] Zhang W, Li N, Chen S, Tan Y, Al-Aidaros M and Chen L. The effects of a tourniquet used in total knee arthroplasty: a meta-analysis. J Orthop Surg Res 2014; 9: 13.
[5] Zhang YQ, Cao QG, Zhao JN, Bao NR and Lu J. The relationship between different tourniquet pressures in total knee arthroplasty and the pain and swelling of the affected limb after surgery. Journal of Medical Postgraduates 2018; 31: 617-621.
[6] Yao Y and Sun XM. Clinical observation on modified setting of pneumatic tourniquet pressure in lower limb surgery. Surg Res N Tech 2019; 8: 211-215.
[7] Zhou JG, Hu WQ, Bi SR, Hu BJ, Liu SW, Xiong L and Qian R. Clinical application of individualized tourniquet pressure in primary total knee arthroplasty. Chinese Journal of Tissue Engineering Research 2019; 23: 3136-3142.
[8] Liang HQ and Su QP. Apply and nursing care of tourniquets during operation of extremities. World Latest Medicine Information 2019; 19: 56-65.
[9] Bogdan Y and Helfet DL. Use of tourniquets in limb trauma surgery. Orthop Clin North Am 2018; 49: 157-165.
[10] Li Z, Liu D, Long G, Ke G, Xiao A, Tang P and Dong J. Association of tourniquet utilization with blood loss, rehabilitation, and complications in Chinese obese patients undergoing total knee arthroplasty: a retrospective study. Medicine (Baltimore) 2017; 96: e9030.
[11] Yassin MM, Harkin DW, Barros D'Sa AA, Halliday MI and Rowlands BJ. Lower limb ischemia-reperfusion injury triggers a systemic inflammatory response and multiple organ dysfunction. World J Surg 2002; 26: 115-121.
[12] Clarke MT, Longstaff L, Edwards D and Rushton N. Tourniquet-induced wound hypoxia after total knee replacement. J Bone Joint Surg Br 2001; 83: 40-44.
[13] McMillan TE, Gardner T and Johnstone AJ. Current concepts in tourniquet uses. Surgery (Oxford) 2020; 38: 139-142.
[14] Van der Spuy L. Complications of the arterial tourniquet. South Afr J Anaesth Analg 2012; 18: 14-18.
[15] Wong S and Irwin MG. Procedures under tourniquet. Anaesth Intensive Care Med 2015; 16: 93-96.
[16] Huwae TECJ, Ratnawati R, Sujuti H, Putra BSS, Putera MA and Hidayat M. The effect of using torniquets on fracture healing disorders: a study in wistar strain rats (Rattus norvegicus). Int J Surg Open 2020; 23: 48-52.
[17] Kumar K, Railton C and Tawfic Q. Tourniquet application during anesthesia: "what we need to know?". J Anaesthesiol Clin Pharmacol 2016; 32: 424-430.
[18] Morrison SR, Magaziner J, McLaughlin MA, Orosz G, Silberzweig SB, Koval KJ and Siu AL. The impact of post-operative pain on outcomes following hip fracture. Pain 2003; 103: 303-311.
[19] Zhu SL, Yao QQ, Xu Y, Wei B, Tang C and Wang LM. Effect of periodic use of tourniquet on joint function rehabilitation after total knee arthroplasty. Journal of Nanjing Medical University (Natural Sciences) 2020; 40: 1054-1062.