Orthopaedic Surgery

CLINICAL ARTICLE

Management of Open Calcaneal Fractures with Medial Wounds by One-Stage Sequential Reduction and Frame Structure Fixation Using Percutaneous Kirschner Wires

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Objective: To assess the clinical outcomes of open calcaneal fractures with medial wounds treated with one-stage management, including early modern wound care, sequential reduction, and frame structure fixation using percutaneous Kirschner wires.

Methods: A total of 19 patients with open calcaneal fractures admitted to our hospital from May 2016 to March 2019 were selected in this study. Twelve type-II and seven type-IIIA medial open injuries were identified according to the classification of Gustilo and Anderson. Fractures were stratified by Sanders classification, including nine type-II fractures, seven type-III fractures, and three type-IV fractures. All patients accepted one-stage irrigation and debridement, sequential reduction of calcaneal fractures through the open medial wound, percutaneous Kirschner wire fixation, and primary closure of wounds covered with vacuum-assisted closure (VAC) device. The Bohler angle, the Gissane angle, and the width of the calcaneus were compared before and after surgery. The functional results were evaluated according to the Paley and Hall score system, visual analogue scale (VAS), American Orthopaedic Foot and Ankle Society (AOFAS) ankle and hindfoot score, Maryland Foot Score, and related complications.

Results: The follow-up duration for all patients ranged from 14 to 28 months (mean, 22.7 months). The angle of Bohler and Giasane was increased from ($-7.6^\circ \pm 15.0^\circ$) and ($96.6^\circ \pm 7.6^\circ$) before surgery to ($23.7^\circ \pm 6.1^\circ$) and ($124.1^\circ \pm 7.1^\circ$) postoperatively ($P < 0.05$), respectively. Three cases of superficial infection and two cases of wound dehiscence were observed in our study, which were then successfully treated with wound debridement, VAC replacement, appropriate use of antibiotics, and delayed closure. The last follow-up revealed three cases of lateral wall expansion and six cases of mild-to-moderate subtalar arthritis based on the Paley and Hall scoring system. According to the AOFAS ankle and hindfoot score, one case showed excellent results, 14 cases exhibited good results, and four cases displayed fair results, with the mean of 80.7 ± 6.7 points (range, 70–90). The Maryland Foot Score revealed one case of excellent outcomes, nine cases of good outcomes, and nine cases of fair outcomes with an average of 76.8 ± 8.6 points (range, 62–90). The mean VAS for pain was 1.8 ± 1.5 (range, 0–5), and a total of 14 patients complained of mild-to-moderate pain when walking for a more extended period. Severe complications, such as deep infection, osteomyelitis, and soft tissue necrosis, were not observed during follow-up.

Conclusions: Collectively, one-stage management allowed the direct restoration of calcaneal morphology with a minimal invasion of soft tissues in most open calcaneal fractures with medial wounds, and the functional outcomes were comparable to previous data.

Key words: Calcaneal fractures; Kirschner wires; Open injury; Percutaneous fixation

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Received 6 October 2020; accepted 22 November 2020

Introduction

Open calcaneal fractures are relatively rare injuries, accounting for 0.8% to 10% of all calcaneal fractures in clinical practice, and are usually caused by high-energy axial loading mechanisms[1, 2]. Because the calcaneal tuberosity is positioned lateral to the weight-bearing alignment of the lower limb, the calcaneus is prone to valgus collapses when bearing a high-energy axial load. Severe calcaneus valgus deformity can increase the tension in medial hindfoot with resultant disruptive injuries of the medial skin[3]. Hence most of open calcaneal fractures are accompanied with medial wounds. The open medial wounds usually consist of two types: skin lacerations exposing the calcaneus and stellate tearing in which a part of the calcaneus can extrude through the medial wound and the time to heal after direct primary repair is prolonged[4]. In addition, the open injury can be further graded into three different Gustilo classifications according to the disruptive extent of medial soft tissue envelop[5]. Therefore, the degree of soft tissue injury following open calcaneal fracture appears to be the most critical variable in these complex injuries.

At present, the optimal treatment has not reached a consensus on open calcaneus fractures as these injuries are further complicated by the traumatic wounds and compromised bone and soft tissue envelope[6]. Because of calcaneal unique anatomical structure and weak soft tissue coverage, the postoperative complications may be severe, especially in those with high-grade open injuries[7, 8]. Previous studies have concluded that complications related with open calcaneal fractures occur in up to 78% of injuries, which include infection in 10% to 39%, soft-tissue problems in 44%, and eventual amputation in 0% to 14%[9]. Management of open calcaneal fractures mainly aims to avoid the soft tissue problems associated with the traumatic wounds, restoring the bony and chondral stabilization, and achieving a favorable hindfoot function[3]. Balancing the priorities between the risk of wound complications and the benefit of improved bone and articular alignment has become an essential ingredient for these high-energy injuries.

Since only a few studies have investigated small amounts of patients with conflicting complication rates and no standardized treatment strategy has formed, previous studies on the surgical treatment for open calcaneal fractures are limited compared with closed calcaneal fractures[10]. Although an anatomic reduction with stable internal fixation can maximally restore the joint function for intra-articular fractures, whether open calcaneal fractures should be treated with open reduction and internal fixation (ORIF) remains uncertain[11]. It is well recongnized that initial treatments, including standard irrigation and debridement, use of antibiotics and VAC coverage, have already reached consensus. However, management of osteosynthesis is still controversial. The treatment concept for managing open calcaneal fracture mainly includes the following aspects. (i) Early management should focus on the protection of soft tissue envelope, and definitive stabilization should be avoided at the time of debridement[12]. (ii) For Gustilo type-I and type-II open fractures with medial wounds, early open reduction and internal fixation can be performed after debridement. For type-III open fractures, early internal fixation should be avoided due to the high rates of wound infection and osteomyelitis[11]. (iii) A standard staged protocol is proposed, including early irrigation and debridement, simple stabilization or minimally invasive fixation, and then definitive fixation until the wounds are stable and soft-tissue swelling is minimal[10]. Based on the literature review, many investigators have already realized the importance of salvaging the soft tissue envelope, which appears to be an essential factor determining the outcome in open calcaneal fractures.

At present, a majority of scholars have proposed a standard staged treatment to manage open calcaneal fractures[3, 4, 8]. Moreover, a series of published studies have demonstrated that utilizing the standardized protocol can reduce the complication rates related with injuried bone and soft tissues[10]. Nevertheless, an additional extensile lateral incision is probably associated with the risk of postoperative wound infections, adding to the costs and prolonging the duration of hospital stays, particularly for those with high-grade soft-tissue injuries. Heier *et al.*[11] has reported that 50% of type-III open fractures managed with the staged extensile lateral approach are complicated by an infection, with osteomyelitis occurring in 27% of cases. If an early surgical solution can restore the calcaneal morphology and obtain the major goals of surgery without unduly increased risks of potential soft-tissue complications, it seems attractive for these challenging injuries. Beltran and Collinge[13] have shown that early open reduction through the medial wounds and percutaneous screw fixation in open calcaneal fractures effectively decreases complication rates with satisfactory early–midterm outcomes.

Consequently, in the present study, we presented a one-stage approach, which was minimally invasive and systematic for the reduction and fixation of calcaneal fractures. Therefore, we aimed to: (i) evaluate the efficiency of one-stage management, including early irrigation and debridement, sequential reduction through the medial open wounds, frame structure fixation using percutaneous Kirschner wires, and use of vacuum-assisted closure (VAC); (ii) compare the functional results and complication rates with previously published reports on open calcaneal fractures; and (iii) analyze the advantages and deficiencies of such a technique.

Materials and Methods

Inclusion and Exclusion Criteria

Inclusion criteria were set as follows: (i) patients suffered from open calcaneal fractures with medial wounds of Gustilo type-II or type-IIIA injuries, and allowed primary closure without skin flap transplantation; (ii) one-stage Kirschner wire fixation was performed after the initial debridement and irrigation; (iii) preoperative and postoperative Bohler angle, Gissane angle, and calcaneal width of the calcaneus; (iv) outcome evaluation was based upon the Paley and Hall score system, visual analogue scale (VAS), American Orthopaedic Foot and Ankle Society (AOFAS) ankle and hindfoot score, Maryland Foot Score, and related complications; (v) a retrospective study.

Exclusion criteria were set as follows: (i) skeletal immaturity; (ii) severe injuries with soft tissue defects requiring skin flap transplantation; (iii) the time from injury to emergency treatment was more than 12 hours; (iv) the follow-up time was less than 12 months; and (v) the patient had a pre-injury mobility dysfunction.

Participants

Based on the above-mentioned inclusion and exclusion criteria, 19 consecutive patients with open calcaneal fractures were identified at our institution from May 2016 to March 2019. These patients included nine males and 10 females, with a mean age of 39 years (range, 21 to 59). Nine cases were caused by falling from heights, seven injuries were attributed to the crushing injury caused by the heavy object, and three injuries occurred during traffic accidents. Besides, seven patients were associated with other fractures, including medial malleolus in three cases, talus fracture with dislocation in two cases, and tibial fracture in one case (Table 1).

At the emergency department, the degree of soft tissue injury was judged by the surgeon. All patients were subjected to the lateral and Harris fluoroscopic views to record the Bohler and Gissane angles as well as calcaneus width, and computed tomography (CT) scan of the affected limb was adopted to assess the fracture classification. According to the classification of Gustilo and Anderson[5], there were seven cases of type-II and 12 cases of type-IIIA open medial injuries. The calcaneal fractures were stratified by Sanders classification[14], consisting of nine cases of type-II, seven cases of type-III, and three cases of type-IV fractures. Emergent treatments, including bandaging, antibiotics, and tetanus prevention, were given to all patients. This study was approved by the medical ethics committee of our institution and informed consent was obtained from all patients.

Surgical Technique

Once the surgery was allowed, the patients were taken to the operating room and subjected to thorough debridement and irrigation on the medial wound to remove contaminated and inactivated soft tissues. Subsequently, one-stage sequential reduction and percutaneous fixation using Kirschner wires were performed. The key procedures of surgical technique were illustrated in Fig. 1. Restoration of the calcaneal medial column was the first step, which could be manipulated directly through medial wounds. A 4.0-mm Kirschner wire was used as a joystick and placed in the posteroinferior side of the calcaneal tuberosity. With the ankle in a dorsiflexion position, the joystick was pulled toward the lateral planta, by which the calcaneal varus could be corrected and the calcaneal length could be restored, followed by drawing of the Kirschner wire downward to control the calcaneal height. The primary posteromedial fracture line and the sustentacular tail fragment could be visualized entirely, which were then reduced through the medial wounds (Fig. 2). If fluoroscopy confirmed a satisfactory calcaneal shape and hindfoot alignment, two paralleled 1.6-mm K-wires were inserted from the tuberosity into the medial

TABLE 1 Patient demographics and characteristics

Case No.	Sex/Age (years)	Follow-up (months)	Mode of Injury	Open Fracture Type	Fracture Type	Other Injuries
1	F (21)	14	Fall	IIIA	II	Medial malleolus fracture
2	F (42)	28	Crush	II	III	No
3	M (33)	18	Traffic accidents	IIIA	III	No
4	M (26)	22	Crush	IIIA	II	No
5	F (39)	24	Crush	II	II	Medial malleolus fracture
6	M (22)	26	Crush	IIIA	III	No
7	F (29)	22	Fall	IIIA	IV	No
8	F (49)	18	Fall	IIIA	III	No
9	M (55)	25	Fall	IIIA	II	Talus fracture
10	F (36)	16	Crush	II	IV	No
11	M (57)	28	Fall	IIIA	II	No
12	F (31)	24	Traffic accidents	II	III	Talus fractue
13	F (48)	22	Fall	IIIA	II	No
14	M (24)	24	Crush	II	III	No
15	F (59)	24	Fall	IIIA	II	Medial malleolus fracture
16	M (52)	21	Fall	IIIA	IV	No
17	M (33)	25	Traffic accidents	II	II	No
18	F (42)	26	Fall	II	II	No
19	M (52)	25	Crush	IIIA	III	Tibial fracture

NOTE: F, female; M, male.

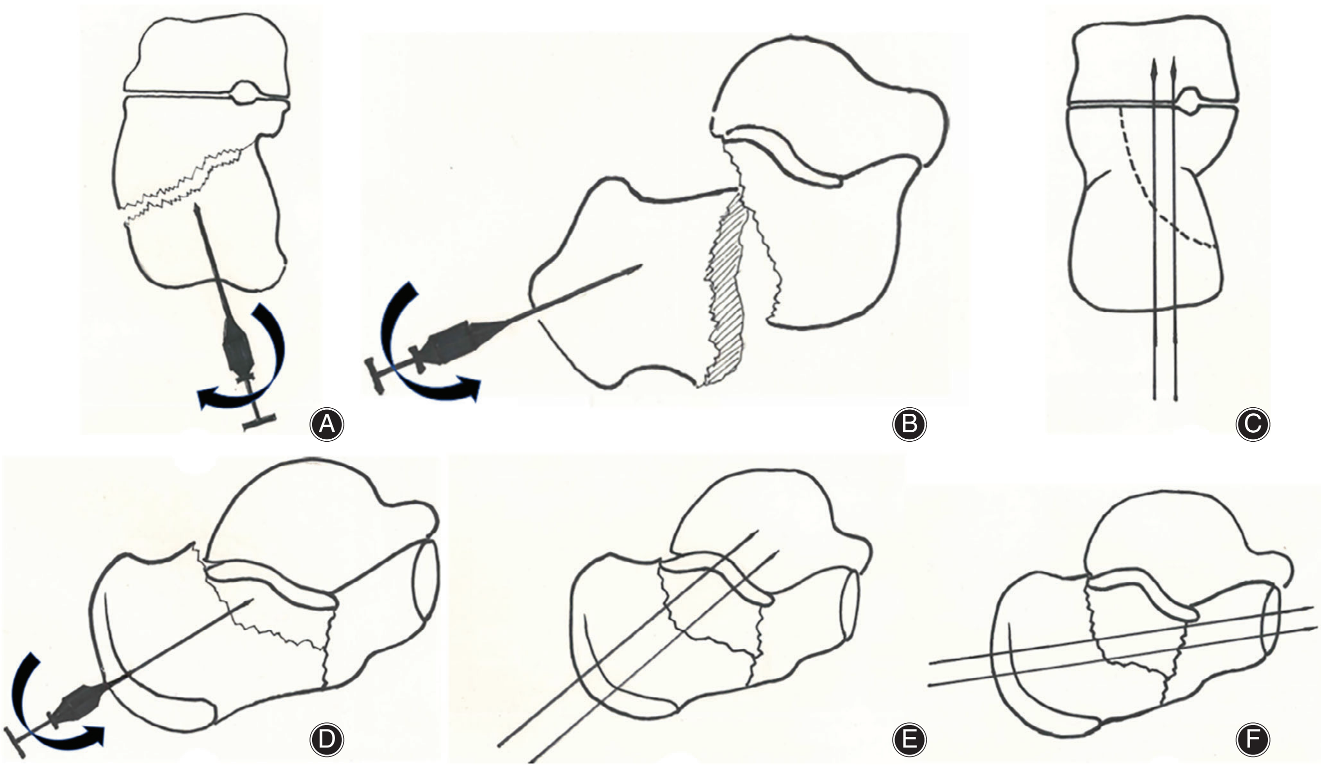

Fig. 1 Manual sketch of the key procedures of one-stage reduction and fixation. (A) Correction of the hindfoot alignment. (B) Resotration of the calcaneal shape. (C) Fixation of the calcaneal medial column. (D) Reduction of the calcaneal posterior facet. (E) Fixation of the calcaneal posterior facet. (F) Fixation of the anterior fragment.

sustentacular tail fragment and advanced to the talus to maintain reduction (Fig. 3).

The reduction of the posterior facet fragments was the second step and carried out with percutaneous leverage. A 4.0-mm Kirschner wire was used as leverage and inserted from the interior of the Achilles tendon's insertion into the posterior facet fragment. With the ankle in a plantar flexion position, the operator pulled the Kirschner wire downward to elevate the posterior facet fragment until the Bohler and Gissane angles were improved. The calcaneal width was restored by squeezing the heel with clasped hands to reduce lateral wall displacement. Two paralleled Kirschner wires were then percutaneously placed from the tuberosity into the posterior facet to maintain reduction (Fig. 4).

The fixation of the anterior fragment was the third step, and the optimal entry point was slightly higher compared with the former two sets of Kirschner wires. The same technique using Kirschner wires was adopted to penetrate the calcaneal tuberosity into the cuboid (Fig. 5). Finally, if there was an avulsion fracture of the calcaneal tuberosity, the fracture fragment was fixed with 1–2 compressive screws percutaneously to resist the muscle tension of the triceps.

All wounds were managed with primary closure and covered with a VAC device, which was changed every 5 days and discontinued after medial wounds were stabilized.

Postoperative Management

Postoperative analgesia and routine antibiotics were used to prevent infection. Weight-bearing and other vigorous activities were restricted for 10–12 weeks after surgery. The Kirschner wires in the calcaneus were removed 3 months postoperatively. Each patient was followed up with the clinical and radiographic examinations at 1, 3, 6, and 12 months as well as the last follow-up to assess the curative effect and related complications.

Outcome Evaluation

The outcome evaluation consisted of clinical examination and radiographic assessment, which was manipulated by two surgeons who were not involved in the operation.

Radiographic Evaluation: The Bohler Angle, the Gissane Angle, and the Calcaneal Width

The Bohler angle was formed by the intersection of two lines, where one line was drawn from the highest point of the anterior process to the highest point of the posterior facet of the calcaneus, and another line was drawn tangent to the superior edge of the calcaneal tuberosity on the lateral view. The usual range of the Bohler angle was 20° to 40°.

Fig. 2 Restoration of the calcaneal medial column. (A) Utilizing the joy-stick technique to correct calcaneal varus and restore the length and height of the calcaneus. (B) Reduction of the sustentacular tail fragment through the medial wounds.

The Gissane angle was formed by the subchondral bone of the posterior facet and middle and anterior facets on the lateral view. This angle individually varied between 120° and 145°.

The calcaneal width was measured on the Harris view, which was the distance between the tangent line on the medial wall and the lateral wall.

Paley and Hall Scoring System

The Paley and Hall scoring system[15] was used to assess the changes in subtalar osteoarthritis. The degree of degeneration of the subtalar joint was divided into three levels. Standard joint space with no evidence of degeneration was set as Grade 0. Normal joint space with the occurrence of osteophytes, subchondral sclerosis, and cysts was set as Grade 1. Joint space narrowing was set as Grade 2. Disappeared joint space was set as Grade 3.

Visual Analogue Scale (VAS)

The VAS scoring system was used to assess the intensity of pain in patients. The VAS pain score = 0 was considered painless, 1–3 as mild, 4–6 as moderate, and 7–10 as intense pain.

American Orthopaedic Foot and Ankle Society (AOFAS) Ankle and Hindfoot Score

The AOFAS ankle and hindfoot score was adopted to evaluate the postoperative recovery of hindfoot function,

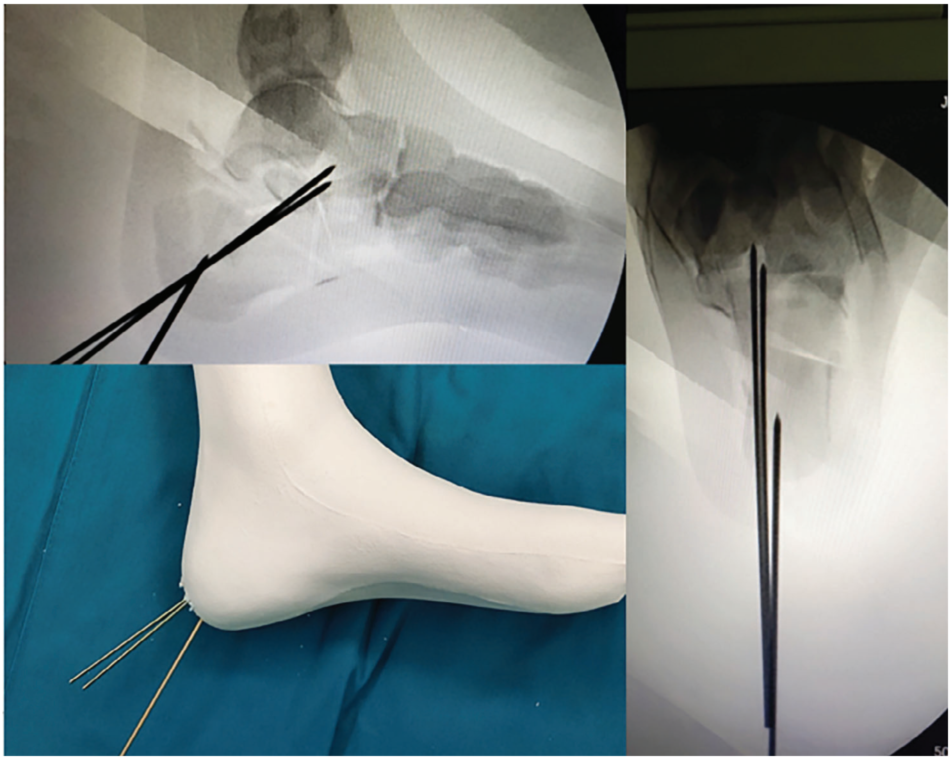

Fig. 3 The lateral and Harris view revealed that the calcaneal medial column was fixed and maintained by two paralleled 1.6-mm Kirschner wires.

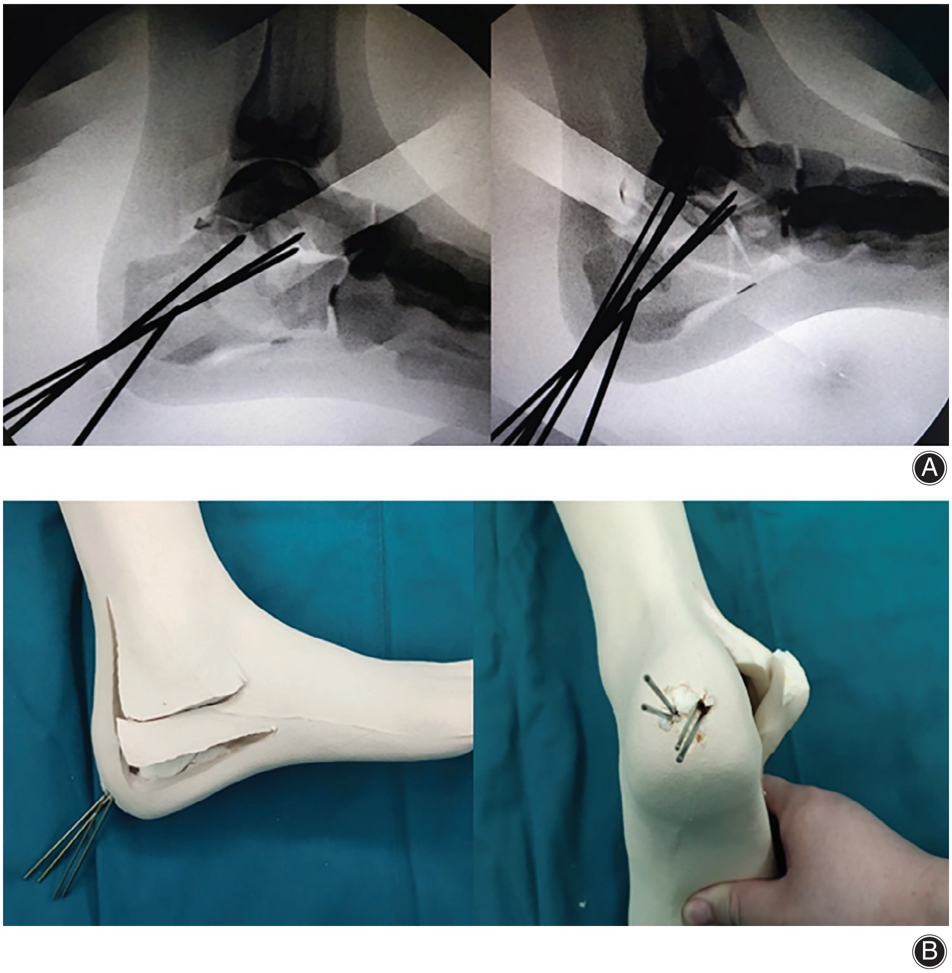

Fig. 4 Restoration of the calcaneal posterior facet. (A) The lateral view showed that the posterior facet was reduced by percutaneous Kirschner wire and then stabilized by two Kirschner wires. (B) General appearance after percutaneous fixation.

which mainly included the following aspects: pain, the function of activities, the ability of support by foot, maximum walking distance, the extent of walking difficulty, abnormal gait, range of motion in the foot, stability, and alignment of ankle and hindfoot. A total score of <50 was considered poor, 50–74 as fair, 75–89 as good, and 90–100 as excellent.

Maryland Foot Score

The Maryland Foot Score[17] was an assessment for foot disorders, mainly consisting of the following items: pain, gait, functional activities, and cosmesis. The scale scores had a minimum of 0 points and a maximum of 100 points. A total score of <50 was considered as poor, 50–74 as fair, 75–89 as good, and 90–100 as excellent.

Complications

The common complications after surgery in the open calcaneal fractures were assessed by clinical examinations and radiographic evaluations, such as infection, wound problems, osteomyelitis, soft tissue necrosis, fixation failure causing the loss of reduction, hindfoot deformity, lateral wall expansion, and post-traumatic subtalar arthritis.

Statistical Analysis

All statistical analyses were performed using SPSS 22.2 software (IBM Software, Chicago, USA). All quantitative data were statistically analyzed using the Student's *t*-test. $P < 0.05$ was considered statistically significant.

Results

A total of 19 patients participated in the current analysis with an average follow-up of 22.7 months (range, 14 to 28). Figures 6–8 illustrate the typical cases.

The Bohler Angle, the Gissane Angle, and the Width of the Calcaneus

The Bohler angle was increased from −7.6° ± 15.0° (range, −37° to 10°) preoperatively to 23.7° ± 6.1° (range, 12° to 32°) postoperatively ($P = 0.0028$). The average preoperative Gissane angle was 96.6° ± 7.6° (range, 81° to 110°), which was increased to 124.1° ± 7.1° (range, 114° to 136°)

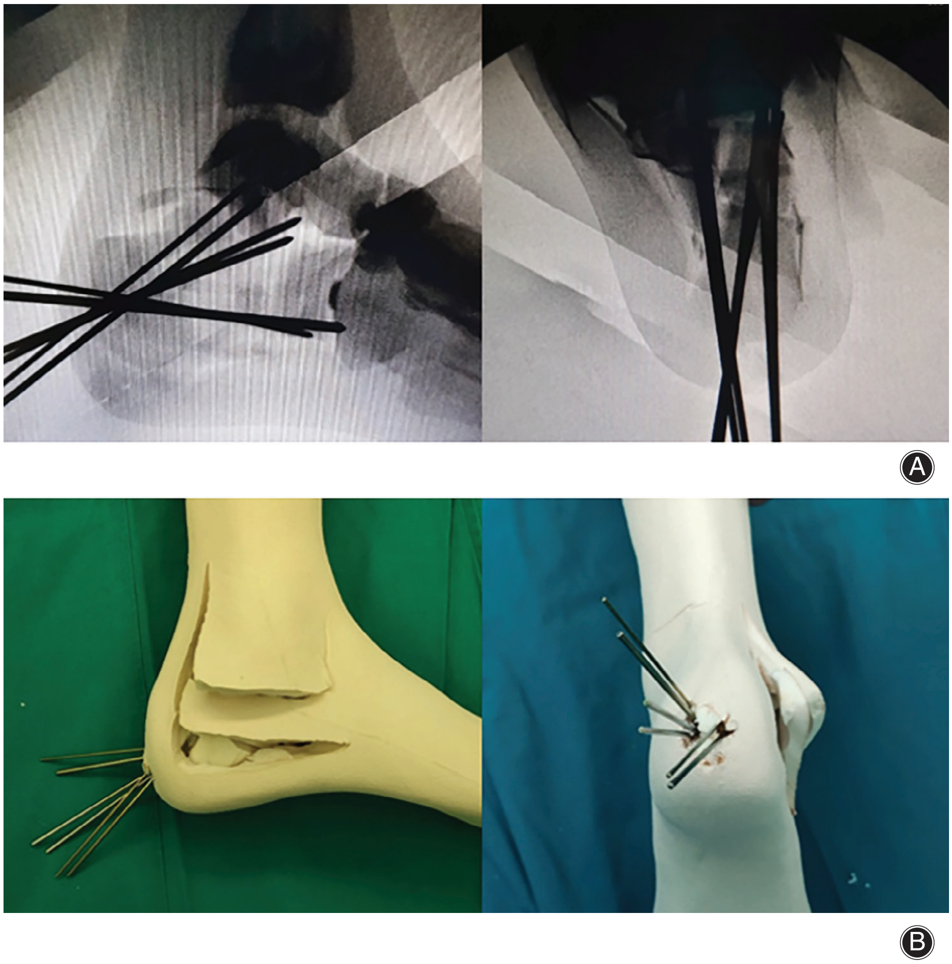

Fig. 5 Fixation of the anterior fragment. (A) The lateral and Harris views showed that the anterior fragment was fixed by two paralleled Kirschner wires. (B) General appearance after percutaneous fixation.

postoperatively ($P = 0.0006$). The width of the calcaneus was decreased from 48.3 ± 3.6 mm (range, 47 to 52) preoperatively to 46.6 ± 2.1 mm (range, 44 to 50) postoperatively ($P = 0.0013$) (Table 2).

Paley and Hall Scoring System

Based on the criteria of the Paley and Hall scoring system used to evaluate post-traumatic subtalar arthritis, there were 13 cases of Grade 0 (68.4%), five cases of Grade 1 (26.3%), and one case of Grade 2 (5.2%) .

Visual Analogue Scale (VAS)

The VAS for pain was 1.8 ± 1.5 (range, 0–5) at the last follow-up. A total of 11 patients complained of mild pain, and four patients suffered from moderate pain in hindfoot when walking for a more extended period, which might be associated with subtalar arthritis or lateral wall expansion deformity.

AOFAS Ankle and Hindfoot Score

According to the AOFAS ankle and hindfoot score, one case showed excellent results, 14 cases exhibited good results, and four cases displayed fair results, with the mean of 80.7 ± 6.7 points (range, 70–90) at the last follow-up. The rate of good to excellent reached up to 78.9%.

Maryland Foot Score

The follow-up result revealed one case of excellent outcomes, nine cases of good outcomes, and nine cases of fair outcomes based upon the Maryland Foot Score, with an average of 76.8 ± 8.6 points (range, 62–90) at the last follow-up.

Complications

There were three cases of superficial infections (15.7%) and two cases of wound dehiscence (10.5%) in open injuries, which were then successfully treated with secondary wound debridement, VAC replacement, appropriate use of antibiotics, and delayed closure. Severe complications, such as deep infection, osteomyelitis, and soft tissue necrosis, were not observed during follow-up. Radiographic examination revealed three cases of lateral wall expansion. Patients with mild-to-moderate subtalar arthritis and lateral wall expansion might require surgery later, including subtalar joint fusion and lateral osteotomy.

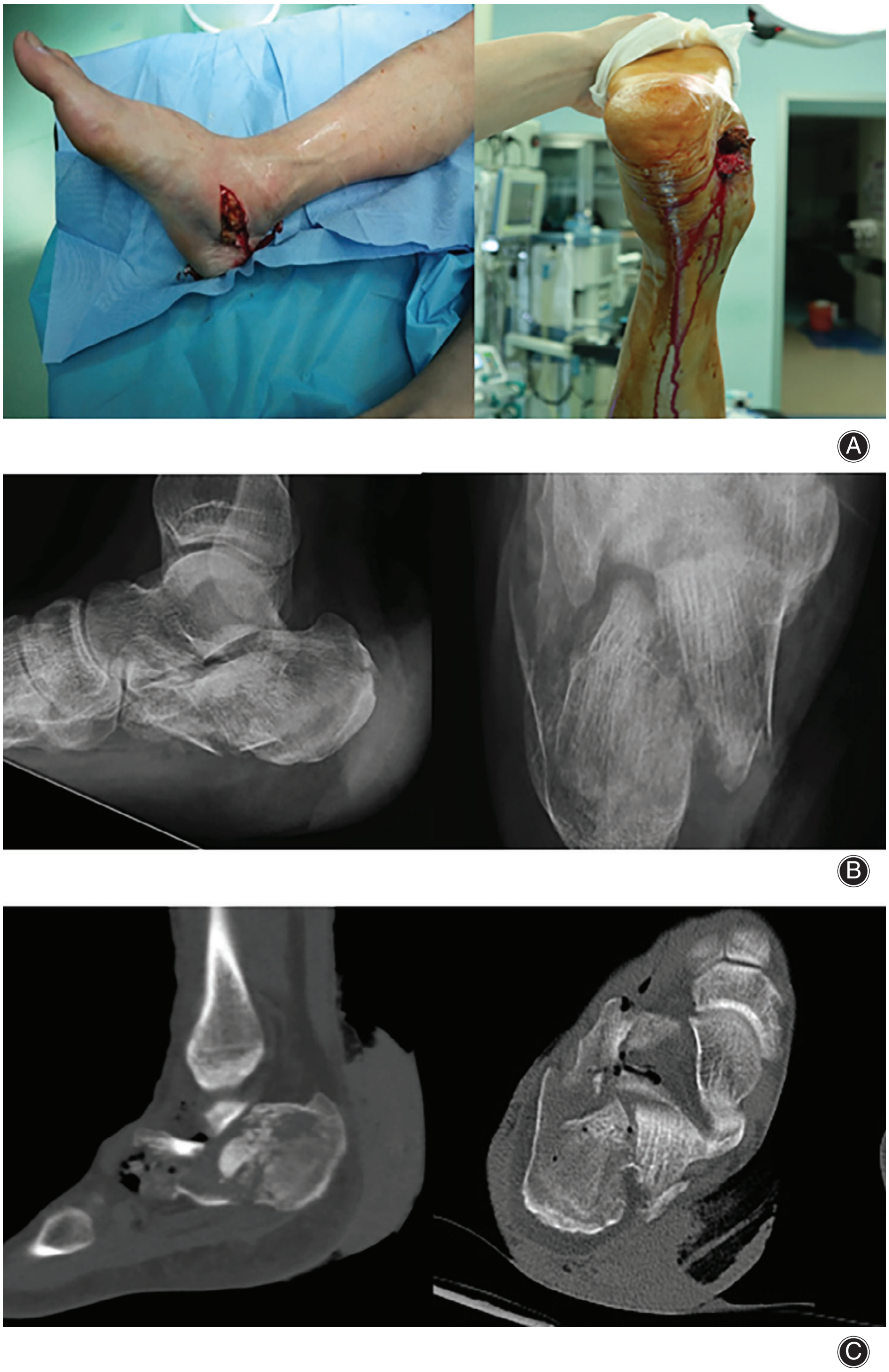

Fig. 6 A right open calcaneal fracture in a 33-year-old man (Table 1, case 3). (A) The patient suffered from a traffic accident and had a Gustilo type-IIIA open injury on the medial side of the hindfoot. (B) The lateral and Harris views showed a joint-depression type of calcaneal fracture with calcaneal varus. (C) The CT scan revealed a Sanders type-IIIAB fracture with subsidence of the posterior facet.

Discussion

The calcaneus often fractures into four to five significant fragments, mainly including tuberosity fragment, medial sustentacular tail fragment, posterior facet fragment, anterior process fragment, and anteromedial fragment[18, 19]. These fragments always need to be fixed with a calcaneal plate or Kirschner wires.

Benefits of Early Reduction and Fixation

For open calcaneal fractures, previous studies have recommended that the primary emphasis of treatment should be focused on the salvage of the soft tissue envelope and prevention of infection, rather than fracture reduction and stabilization[20]. However, it has been well recognized that early stabilization of the bony architecture can improve soft tissue

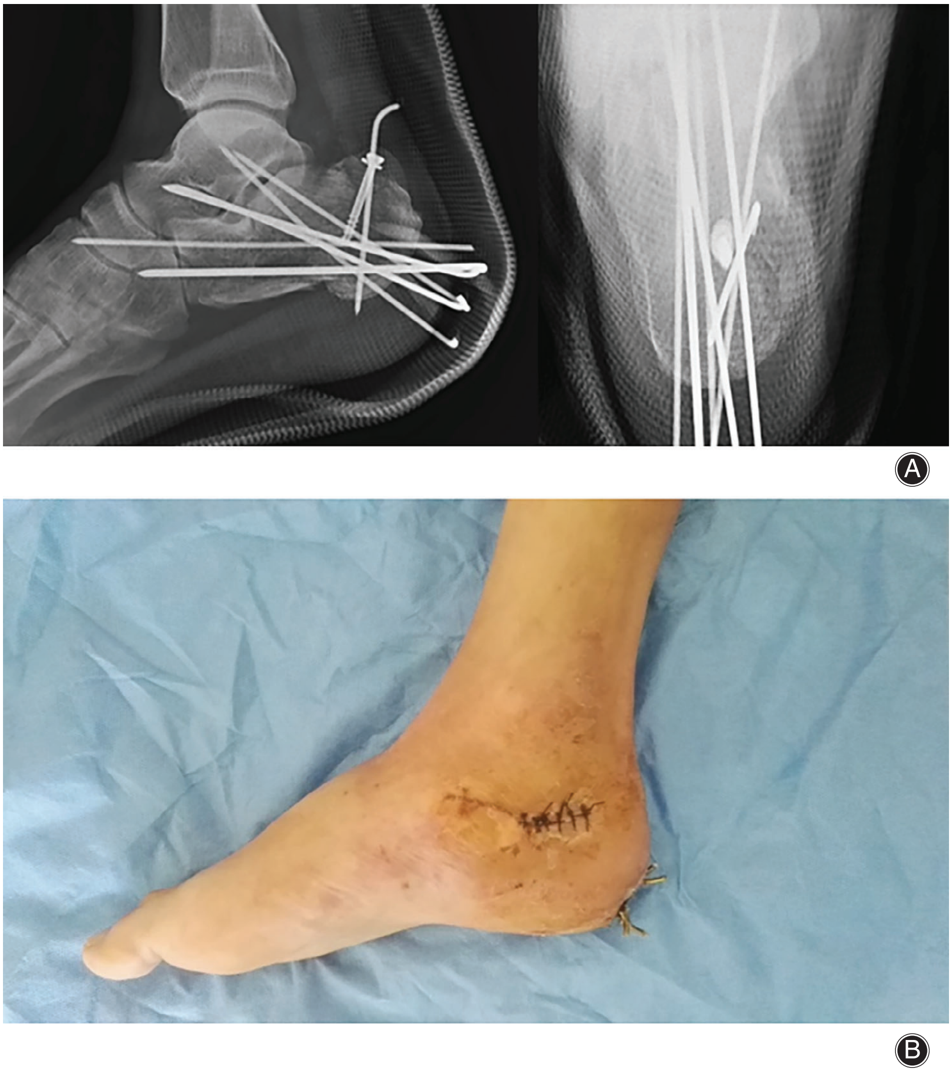

Fig. 7 Postoperative X-rays and state of wound healing. (A) The postoperative lateral and Harris views showed that a satisfactory restoration of calcaneal morphology and hindfoot alignment. (B) Open traumatic wound was healed at 2 weeks after surgery without soft tissue necrosis, infection, and other complications observed.

management[21]. In the period of waiting for wound healing, the hematoma begins fibrous union and soft tissue shrinking, which may cause more complicated secondary reduction[22, 23]. Moreover, the prominent medial sustentacular tail fragment may increase wound tension, disrupting the blood supply of soft tissues, and affecting wound healing. Zhang *et al.*[24] has considered that emergency reduction and fixation can correct calcaneal deformity, decreasing the soft tissue compression and creating advantageous conditions for wound healing. Therefore, early reduction of the fracture is crucial to relieve stress on the medial wounds, which may allow tension-free closure.

In the present study, open medial wounds provided portal and direct access for medial stabilization with the visualization of reduction of the medial column, which was lesser complicated compared with ORIF through a lateral approach. Restoration of the calcaneal medial column offers immediate mechanical stability and minimizes wound tension to promote wound healing. Meanwhile, the use of Kirschner wires penetrating the medial sustentacular tail fragment from the tuberosity and reaching the talus can ensure the stability of the medial column to the most considerable extent. This procedure directly corrects the calcaneal varus deformity with a normal hindfoot alignment obtained, offering rigid support on the medial wall to maintain calcaneal morphology.

Comparison of Staged Treatment with One-stage Management

Initial treatment, including standard irrigation and debridement, use of antibiotics, and VAC coverage, has reached a consensus, while management of osteosynthesis is still disputable[3, 12, 25]. Many studies have proposed that definitive stabilization should be avoided on the day of injury because of the catastrophic results, and they suggested a staged fixation or minimally invasive technique[6, 11, 12]. Mehta *et al.*[4] has shown that staged reconstruction through lateral approach following initial fracture pinning is safe and

Fig. 8 Functional outcomes of the foot and ankle at 18 months of follow-up. The patient had a good range of motion in both foot dorsiflexion and plantar flexion without arch collapse.

TABLE 2 Radiographic evaluation before and after surgery

Parameter	Pre-operation	Post-operation	*P* value
Bohler(°)	−7.6 ± 15.0	23.7 ± 6.1	0.0028
Gissane(°)	96.6 ± 7.6	124.1 ± 7.1	0.0006
Width(mm)	48.3 ± 3.6	46.6 ± 2.1	0.0013

effective, which can avoid related wound complications. Brent Wiersema[10] has reported 127 patients treated with delayed definitive fixation until the soft tissue swelling subsides. In this series, the occurrence of superficial wound infection and deep wound infection is 9.6% and 12.2%, respectively. The rate of amputation and osteomyelitis is respectively 5.2%. In a previous study reported by Seibert *et al.*[20], who did not follow a staged approach, the overall complication rate exceeds 60%. Hence, utilizing the standard treatment can reduce complication rates. However, there is a strong possibility that the staged extensile lateral approach is associated with the risk of postoperative wound infections and even osteomyelitis, leading to a more complicated treatment process.

If one-stage management can realize major treatment targets, many complications related to the delayed surgery can be avoided, the treatment cycle shortened, and hospitalization costs minimized. Therefore, we selected one-stage percutaneous Kirschner wire fixation as the definitive treatment and aimed to minimize the risks of catastrophic complications, providing an acceptable result that the bone and articular anatomy might be improved but perhaps not reduced completely. In our present study, the occurrence of superficial infections and wound dehiscence was 15.7% and 10.5%, respectively. The mean AOFAS score for the series was 80.7. The functional outcomes of our patients and the complication rate were comparable to other recent reports on open calcaneal fractures managed with staged extensile lateral approaches[4,10,11]. Although six cases with subtalar arthritis in our study might require later hindfoot fusion, to some extent, this technique substantially reconstructed the calcaneal shape and hindfoot alignment, preserving much of the foot function and creating an effective treatment foundation for later subtalar arthrodesis. Especially for some patients with a poor skin and soft tissue condition, or those with multiple traumas and intolerance to secondary surgery, it seemed more appropriate to use one-stage percutaneous reduction and fixation as a definitive treatment.

Security of Percutaneous Kirschner Wire Fixation

To decrease the incidence of wound complications, many investigators have proposed minimally invasive techniques, such as percutaneous Kirschner wire or screw fixation, to treat these complex injuries[26–28]. Previous literature has successfully confirmed that percutaneous Kirschner wire fixation can be regarded as temporizing or definitive management to treat calcaneal fractures[29]. Lu *et al.*[30] has demonstrated that Sanders type-II and type-III tongue fractures fixed with Kirschner wires have advantages of low cost, quick recovery, and less trauma. Besides, Lawrence[25] has proposed that minimally invasive fixation can be performed in the acute soft-tissue phase without unduly increased risk of infection. Percutaneous Kirschner wire fixation manipulated in open calcaneal fractures vastly decreased the invasion of weak soft tissue and avoided severe complications inherent to ORIF. In the present study, superficial wound infection occurred in three patients who were then successfully treated with secondary wound debridement, VAC replacement, appropriate use of antibiotics, and delayed closure. There was no deep infection, osteomyelitis, and catastrophic problems in our series of cases.

However, percutaneous Kirschner wires might provide lesser rigid fixation than the anatomical plate, and even a loss of the achieved reduction[31]. Abdelgaid[32] has found that three cases treated by closed reduction and percutaneous fixation develop loss of reduction and propose not bearing weight before 12 weeks. Dorr *et al.*[33] has reported that four of 69 K-wires (5.8%) had a secondary dislocation, but none of the bent K-wires were observed in the calcaneal fractures. Beltran and Collinge[13] has suggested more percutaneous fixation rather than using fewer amounts of fixation *via* those techniques. A frame fixation structure created by four sets of Kirschner wires offered adequate support for the main fragments in our study. Each Kirschner wire penetrated the talus, subtalar joint, and calcaneocuboid joint from the calcaneal tuberosity, which were both stable and firm entry-points, increasing the grasping strength of the Kirschner wires. With no weight-bearing before 10–12 weeks, none of the displaced Kirschner wires and loss of reduction were revealed in the present study.

Limitations

Firstly, the incomplete reduction of posterior facet was a considerable issue in our study. Restoration of comminuted or severely depressed posterior facet only depending on the percutaneous technique appeared risky and limited. However, we found that the depression extent of the posterior facet could be improved after reduction of the medial column, probably because support from the medial column widened the inter-fragmental gap. Therefore, percutaneous leverage with Kirschner wires inserted into the posterior facet could elevate the most collapsed articular facet from below. Nevertheless, six patients with mild-to-moderate subtalar osteoarthritis were observed because the restoration of the posterior facet failed to reach the anatomical criteria and remained to be reduced. Consequently, the author acknowledged that delayed fixation using the calcaneal plate may obtain a better articular surface reduction. However, an anatomic reduction of the bone alignment and articular surface is often considered as a secondary concern in these complex injuries[10]. Moreover, no controlled studies have evaluated the difference in the curative effect between the one-stage percutaneous fixation and delayed plate fixation. Therefore, it remains uncertain whether it is necessary to replace percutaneous fixation with lateral plate fixation.

Secondly, this technique has a particular learning curve, and repeated adjustment of entry-points of Kirschner wires may lead to failure of percutaneous fixation. Therefore, it is essential to get familiar with the spatial anatomical structure of the calcaneus for this technique, which can effectively reduce the adjustive frequency of insertion points of Kirschner wires.

Finally, the lateral wall of the calcaneus might be restored poorly. It is challenging to reduce the lateral wall, which may lead to lateral wall expansion deformity. Three cases with lateral wall expansion in the present study might require lateral osteotomy.

Conclusion

Open calcaneal fractures with medial wounds are rare injuries that have historically been related to an increased incidence of infection, osteomyelitis, and poor functional results. The one-stage management we manipulated allowed direct restoration of calcaneal morphology with a minimal invasion of soft tissues, and no catastrophic complications were observed. The functional outcomes and complication rates were comparable to previously reported literature on open calcaneal fractures. However, due to the lack of comparison between the patients accepting a staged approach and our series of cases, delayed ORIF might be more applicable. Nevertheless, based on our early to midterm results, our treatment strategy could be applied in such complicated injuries.

Disclosure

The authors declare no conflict of interest. No benefits in any form have been, or will be, received from a commercial party related directly or indirectly to the subject of this manuscript.

References

1. McGarvey WC, Burris MW, Clanton TO, Melissinos EG. Calcaneal fractures: indirect reduction and external fixation. Foot Ankle Int, 2006, 27: 494–499.
2. Barei DP, Bellabarba C, Sangeorzan BJ, Benirschke SK. Fractures of the calcaneus. Orthop Clin North Am, 2002, 33: 263–285 x.
3. Lawrence SJ. Open calcaneal fractures. Orthopedics, 2004, 27: 737–471.
4. Mehta S, Mirza AJ, Dunbar RP, Barei DP, Benirschke SK. A staged treatment plan for the management of type II and type IIIA open calcaneus fractures. J Orthop Trauma, 2010, 24: 142–147.
5. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am, 1976, 58: 453–458.
6. Berry GK, Stevens DG, Kreder HJ, McKee M, Schemitsch E, Stephen DJ. Open fractures of the calcaneus: a review of treatment and outcome. J Orthop Trauma, 2004, 18: 202–206.
7. Benirschke SK, Kramer PA. Wound healing complications in closed and open calcaneus fractures. J Orthop Trauma, 2004, 18: 1–6.
8. Gougoulias N, Khanna A, McBride DJ, Maffulli N. Management of calcaneal fractures: systematic review of randomized trials. Br Med Bull, 2009, 92: 153–167.
9. Dickens JF, Kilcoyne KG, Kluk MW, Gordon WT, Shawen SB, Potter BK. Risk factors for infection and amputation following open, combat-related calcaneal fractures. J Bone Joint Surg Am, 2013, 95: e24–1-8.
10. Wiersema B, Brokaw D, Weber T, *et al*. Complications associated with open calcaneus fractures. Foot Ankle Int, 2011, 32: 1052–1057.
11. Heier KA, Infante AF, Walling AK, Sanders RW. Open fractures of the calcaneus: soft-tissue injury determines outcome. J Bone Joint Surg Am, 2003, 85: 2276–2282.
12. Aldridge JM, Easley M, Nunley JA. Open calcaneus fractures. Results of operative treatment. J Orthop Trauma, 2004, 18: 7–11.
13. Beltran MJ, Collinge CA. Outcomes of high-grade open calcaneus fractures managed with open reduction via the medial wound and percutaneous screw fixation. J Orthop Trauma, 2012, 26: 662–670.
14. Sanders R, Fortin P, DiPasquale T, Walling A. Operative treatment in 120 displaced intraarticular calcaneal fractures. Results using a prognostic computed tomography scan classification. Clin Orthop Relat Res, 1993, 290: 87–95.
15. Paley D, Hall H. Intra-articular fractures of the calcaneus. A critical analysis of results and prognostic factors. J Bone Joint Surg Am, 1993, 75: 342–354.
16. Kitaoka HB, Alexander IJ, Adelaar RS, Nunley JA, Myerson MS, Sanders M. Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. Foot Ankle Int, 1994, 15: 349–353.
17. Myerson MS, Fisher RT, Burgess AR, Kenzora JE. Fracture dislocations of the tarsometatarsal joints: end results correlated with pathology and treatment. Foot Ankle, 1986, 6: 225–242.
18. Miric A, Patterson BM. Pathoanatomy of intra-articular fractures of the calcaneus. J Bone Joint Surg Am, 1998, 80: 207–212.
19. Langdon IJ, Kerr PS, Atkins RM. Fractures of the calcaneum: the anterolateral fragment. J Bone Joint Surg Br, 1994, 76: 303–305.
20. Siebert CH, Hansen M, Wolter D. Follow-up evaluation of open intra-articular fractures of the calcaneus. Arch Orthop Trauma Surg, 1998, 117: 442–447.
21. Tahir M, Chaudhry EA, Zimri FK, *et al*. Negative pressure wound therapy versus conventional dressing for open fractures in lower extremity trauma. Bone Joint J, 2020, 102: 912–917.
22. Rammelt S, Barthel S, Biewener A, Gavlik JM, Zwipp H. Calcaneus fractures. Open reduction and internal fixation. Zentralbl Chir, 2003, 128: 517–528.
23. Tennent TD, Calder PR, Salisbury RD, Allen PW, Eastwood DM. The operative management of displaced intra-articular fractures of the calcaneum: a two-Centre study using a defined protocol. Injury, 2001, 32: 491–496.
24. Zhang T, Yan Y, Xie X, Mu W. Minimally invasive sinus tarsi approach with cannulated screw fixation combined with vacuum-assisted closure for treatment of severe open calcaneal fractures with medial wounds. J Foot Ankle Surg, 2016, 55: 112–116.
25. Lawrence SJ. Open calcaneal fractures: assessment and management. Foot Ankle Clin, 2005, 10: 491–vi.
26. Schepers T, Schipper IB, Vogels LM, *et al*. Percutaneous treatment of displaced intra-articular calcaneus fractures. J Orthop Sci, 2007, 12: 22–27.
27. DeWall M, Henderson CE, McKinley TO, Phelps T, Dolan L, Marsh JL. Percutaneous reduction and fixation of displaced intra-articular calcaneus fractures. J Orthop Trauma, 2010, 24: 466–472.
28. Rammelt S, Amlang M, Barthel S, Gavlik JM, Zwipp H. Percutaneous treatment of less severe intraarticular calcaneal fractures. Clin Orthop Relat Res, 2010, 468: 983–990.
29. Stulik J, Stehlik J, Rysavy M, Wozniak A. Minimally-invasive treatment of intra-articular fractures of the calcaneum. J Bone Joint Surg Br, 2006, 88: 1634–1641.
30. Lu B, Liu P, Wang Y, *et al*. Minimally invasive manipulative reduction with poking k-wire fixation in the treatment of various types of calcaneal fractures. Eur Rev Med Pharmacol Sci, 2015, 19: 4220–4426.
31. Gavlik JM, Rammelt S, Zwipp H. Percutaneous arthroscopically assisted osteosynthesis of calcaneus fractures. Arch Orthop Trauma Surg, 2002, 122: 424–428.
32. Abdelgaid SM. Closed reduction and percutaneous cannulated screws fixation of displaced intra-articular calcaneus fractures. Foot Ankle Surg, 2012, 18: 164–179.
33. Dorr MC, Backes M, Luitse JS, de Jong VM, Schepers T. Complications of Kirschner wire use in open reduction and internal fixation of calcaneal fractures. J Foot Ankle Surg, 2016, 55: 915–917.