Minimally invasive surgery for Sanders type II–III calcaneal fractures with external fixator- assisted poking reduction and percutaneous screw fixation: a 2–5 years clinical and radiographic retrospective cohort study

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Research Article

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Abstract

Background: For intra-articular calcaneal fractures of Sanders type II and above, open reduction and internal fixation could obtain anatomic reduction and firm fixation, however, there are high complications associated with surgery, such as incision infection and subtalar joint stiffness. As another treatment method, poking reduction and percutaneous fixation can reduce the complications. In this study, we introduce a new technique for external fixator-assisted reduction and computer-assisted preoperative design of the poking reduction and percutaneous screw fixation.

Methods: Patients with calcaneal fractures who met the inclusion criteria were treated with external fixator-assisted poking reduction and percutaneous screw fixation at our hospital from March 2017 to September 2019, and the clinical and radiographic outcomes were evaluated.

Results: A total of 31 patients were followed up, 10 cases of Sanders type II, and 21 cases of Sanders type III calcaneal fracture. The mean time from injury to operation was 3.2±1.9 days; the mean hospital stay was 7.3±3.1 days; the mean operation time was 87.74±30.30 min; and the mean intraoperative blood loss was 41.45±34.16 ml. Two patients underwent a change of surgical procedure and one underwent a second operation. Postoperative follow-up radiography showed good reduction of calcaneus length, height, width, Böhler angle, and Gissane angle. Postoperative follow-up CT showed good reduction of the subtalar articular surface in 83.6% of patients. At the last follow-up, the AOFAS score was 93.84±7.92, of which 24 cases were excellent, six cases were good, and one case was acceptable. The average range of motion of flexion and extension of the ankle joint on the injured side was 64.35±1.38°, which was not statistically different from that of the healthy side. The average range of motion of the subtalar joint was 29.27±1.63°, which was 88.6% of the healthy side, and two patients developed subtalar traumatic arthritis.

Conclusion: External fixator-assisted poking reduction and percutaneous screw fixation is a safe and effective minimally invasive surgery for intra-articular calcaneal fractures, which has a lower incidence of postoperative complications and can reduce the impact on subtalar joint mobility, and increase the clinical effect.

Trial registration: Retrospective cohort study.

Background

Calcaneal fractures are the most common tarsal fractures and account for 2% of systemic fractures. Most calcaneal fractures are intra-articular and are caused by axial violence[1]. For intra-articular calcaneal fractures of Sanders type II and above, the reduction of calcaneal morphology and anatomy of the subtalar joint, especially the length, height, width, Böhler angle, and Gissane angle, are key to surgical treatment[2, 3]. However, the anatomical structure around the calcaneus is complex, the local soft tissue coverage is poor, and the incidence of complications related to open reduction and internal fixation, such as incision infection, flap necrosis, sural nerve injury, and subtalar joint stiffness, has been reported to be

16.7–62.5% [4–8]. The sinus tarsi approach for treating intra-articular calcaneal fractures reduces the risk of wound infection, flap necrosis, and sural nerve injury compared to the lateral extensile approach but does not effectively solve the problem of subtalar joint stiffness [9–11]. Closed reduction and percutaneous screw internal fixation, which is another minimally invasive surgery for the treatment of intra-articular calcaneal fractures, can avoid soft tissue injury around the subtalar joint caused by the sinus tarsi approach, thereby improving the range of motion of the subtalar joint after calcaneal surgery. Closed reduction is generally performed with the assistance of an external fixator, subtalar arthroscope, three dimensional (3D) printing, etc. but is associated with poor reduction of the subtalar articular surface and internal fixation failure[7, 12–16]. In addition to the severity of the fracture, the reasons are mainly related to inadequate preoperative planning and improper reduction methods and screw placement. To solve these problems, the Mimics V16.0 software (Materialize, USA) was used to perform a precise preoperative design, split the main fracture mass, simulate reduction with the healthy calcaneus, and then simulate placement screws; at the same time, the position, direction, size, and number of screw placements were recorded as references to the operation in our study. According to the preoperative design, the length, width and angulation deformity of calcaneus were corrected intraoperatively by reverse traction with bilateral external fixators. The posterior facet of the subtalar joint was reduced by poking, under the guidance of border projection radiographs of the calcaneus. Finally, the screw was inserted percutaneously. The problems of poor reduction and internal fixation failure of subtalar articular surface were solved effectively. In this retrospective cohort study, the technical notes and clinical and radiographic follow-up outcomes of 2–5 years of Sanders type II–III calcaneal fractures treated with external fixator-assisted reduction and percutaneous screw fixation were introduced.

Methods

Participants

From March 2017 to September 2019, 31 patients with intra-articular calcaneal fractures who had met our inclusion criteria were treated with external fixator-assisted reduction and percutaneous screw fixation at our hospital.

The inclusion criteria were as follows: 1) age between 18 and 60 years; 2) unilateral intra-articular calcaneal fractures; 3) Sanders II–III fractures; and 4) surgical treatment involving external fixator-assisted reduction and percutaneous screw fixation.

The exclusion criteria were as follows: 1) childhood fracture, osteoporotic fracture, or pathological fracture; 2) bilateral calcaneal fractures; 3) multiple injuries or compound injuries, such as pelvic fracture, spinal cord injury, chest and abdominal injury, burns, etc.; 4) old fractures; and 5) absence of informed consent from patients and their families.

This retrospective study was approved and authorized by the Ethics Committee of the Fourth Medical Center of PLA General Hospital. The description of surgical technique, informed consent, surgical mechanism, expected therapeutic effect, potential risk, and iatrogenic injury was approved.

Surgical instruments

Bastiani external fixator (Xinzhong Medical Instrument Co., LTD., China), self-tapping cortical bone screws with a diameter of 3.5 mm, and cannulated screws with a diameter of 3.0 mm or 4.0 mm (Johnson (Shanghai) Medical Devices Co., Ltd., USA) were used.

Preoperative plan

The type of intra-articular calcaneal fractures were classified according to the Sanders classification[17]. A personalized treatment plan was developed for each patient. A patient with Sanders IIab (Fig. 1) is used as an example to describe the technical notes regarding the treatment of calcaneal intra-articular fractures with external fixator-assisted reduction and percutaneous screw fixation.

Preoperative computed tomography (CT) (Philips Medical Technologies, The Netherlands) with a thickness of 1.25 mm was used to scan the bilateral calcaneus and endoplants. Cortical bone and cannulated screws of different sizes were placed beside next to the heel during examination. The image was converted into Digital Imaging and Communications in Medicine format (DICOM) and downloaded and imported into the Mimics V16.0 software system. Taking the shape of the healthy calcaneus as reference, the system was used to simulate reduction of the mess fracture blocks and the subtalar articular surface (Fig. 2). Cortical bone screws or cannulated screws were placed parallel from the exterior to the interior below the subtalar articular surface, and at least two screws were used to fix each mess fracture. The following parameters were recorded during the simulated reduction and fixation process: the direction and distance of the traction reduction of the main fracture block; direction of elevating compressed subtalar articular surface; and position, direction, and size of the inserted screw for reference during the operation.

Surgical procedures

After general or epidural anesthesia, the patient was positioned on a fluoroscopic table in a lateral position with the injured limb on top; a tourniquet was not required. The G-arm fluoroscopy machine was placed diagonally under the fluoroscopy bed and adjusted to the appropriate position so that the lateral, axial, and Broden projection fluoroscopy could be conveniently carried out during the operation (Fig. 3).

Step 1: Reduce the calcaneal length and height and correct calcaneal varus or valgus (Fig. 4).

Before the surgery, the insertion points of external fixator needles in the talus and calcaneus were located under fluoroscopy. Then, an arc-shaped incision of approximately 2 cm was made at lateral calcaneus, and a part of the lateral calcaneus cortex was exposed by periosteal elevator. Then, two K-wires with a diameter of 3.0 mm were inserted parallelly into the calcaneus and talus according to the positioning of the insertion point. Then, bilateral external fixator was installed on the K-wire. According to the traction direction and distance obtained in the Mimics V16.0 software system before surgery, the bilateral nuts of external fixator were tightened to reduce the length and height of the calcaneus under radiological monitoring. The nut of unilateral external fixation was loosened or continuously tightened to correct calcaneal varus or valgus.

Step 2: Reduce the subtalar articular surface and percutaneous screw fixation (Fig. 5).

A 0.5-cm fissure was opened from the lateral calcaneal incision of the cortical bone, and a periosteal elevator was used to elevate the compressed subtalar articular surfaces. After the anterior, middle, and posterior articular surfaces of the subtalar joint were reduced under radiological supervision of border projections, K-wires were used for temporary fixation. Then, under radiological monitoring, two cannulated screws were implanted from the calcaneal tubercle toward the calcaneocuboid joint, one cannulated screw was implanted from the calcaneal tubercle toward the subtalar joint to maintain the calcaneus length and height, and two cortical bone screws were implanted below the subtalar articular surface to fix the subtalar joint fracture

Step 3: Reduce the calcaneus width and percutaneous screw fixation.

Point contact reduction forceps was placed on the medial and lateral walls of the calcaneus, or both hands were used to compress the calcaneus to reduce the width of the calcaneus. Then a cortical bone screw was inserted from the lateral of calcaneus into the sustentaculum tali to maintain the width of the calcaneus. Before the end of the operation, lateral, axial, and border projection radiographs of the calcaneus were retaken to confirm whether the reduction and fixation were satisfactory. Then, the external fixator was removed, and the wound was sutured.

Postoperative management

Active toe flexion and extension, active ankle flexion and extension, active pronation and inversion, and passive subtalar pronation and inversion activities were performed immediately after surgery. Non-weight-bearing ambulation was begun on the second day postoperatively and partial weight-bearing ambulation at 6 weeks postoperatively. If the calcaneal fracture had healed, the patient could begin full weight-bearing ambulation at 3 months after surgery.

Measurement

The time from injury to surgery and the duration of hospital stay were recorded. The operative time, amount of intraoperative blood loss, and changes in surgical procedures were recorded. After surgery, the patient was observed for wound infection, necrosis and sural nerve injury, etc.. Bilateral lateral and axial calcaneus radiographs, and bilateral calcaneus CT was performed before surgery. Lateral and axial radiographs, and CT of the injured calcaneus were performed on the second day, at 6 months after surgery and at the last follow-up. The length, height, width, Böhler angle, and Gissane angle of calcaneus were measured by radiography, and the reduction of the subtalar articular surface was observed by CT. According to the subtalar articular surface reduction criteria proposed by Kurozumi et al., no step, no defect, or no angulation was considered excellent reduction; step < 1 mm, defect < 5 mm, or angulation < 5° was considered good; step 1–3 mm, defect 5–10 mm, or angulation 5–15° was considered fair; and step ≥ 3 mm, defect ≥ 10 mm, or angulation ≥ 15° was considered poor[18]. At the last follow-up, American Orthopaedic Foot & Ankle Society (AOFAS) scores were obtained, and bilateral ankle and subtalar joint flexion and extension range of motion were examined. Lateral and axial calcaneus x-ray and CT were performed to observe fracture healing and the presence of traumatic arthritis. Traumatic arthritis can be considered when there is joint space narrowing, periarticular bone hyperplasia, or subarticular bone cyst formation[10].

Statistical methods

All data were analyzed using SPSS (Statistical Product and Service Solutions, USA) 26.0. Patient age, operation time, AOFAS score, and other numerical variables were analyzed using descriptive statistics. An independent sample t-test was used to compare the mean range of flexion and extension motion of the bilateral ankle and subtalar muscles. Analysis of variance was used for x-ray and CT follow-up data of the calcaneus, the least significant difference test was used for analysis between different time points, and Tamhane's T2 was used to analyze data that did not meet the homogeneity of variance test. $P < 0.05$ was considered statistically significant.

Results

General outcomes

A total of 34 patients were included in this study, of whom two changed the operation procedure, including one case with open reduction and internal fixation. The other patient's fracture near the calcaneocuboid joint was completely comminuted, a limited skin incision was performed, and a micro-locking plate was inserted after percutaneous poking reduction. One case was lost to follow-up, and 31 cases were followed up. The follow-up period ranged from 24 to 68 months, and the mean follow-up time was 40.19 ± 11.35 months (Table 1).

Table 1
General data of patients

Project	Value
Gender (female/male)	10/21
Age (years)	40.8 ± 9.8
Fracture Left (cases) Right (cases)	13 18
Sanders' Fracture classification □ (cases) □ (cases)	20 21

Clinical outcomes

The average time from injury to surgery was 3.2 ± 1.9 days; the average length of hospital stay was 7.3 ± 3.1 days; the average operative time was 87.74 ± 30.30 min; the average intraoperative blood loss was 41.45 ± 34.16 ml; and the average AOFAS score was 93.84 ± 7.92. According to the AOFAS grading standard, 24 cases (77.4%) were excellent, six cases (19.4%) were good, and one case (2.7%) was acceptable. The average range of flexion and extension motion of the ankle joint on the healthy side was 64.80 ± 1.30°, ranging from 48.4° to 81.3°, while that on the injured side was 64.35 ± 1.38°, ranging from 46.4° to 80.2°, with no statistical difference ($P = 0.811$). The average flexion and extension range of motion of the healthy subtalar joint was 35.05 ± 1.27°, ranging from 18.9° to 47.4°, while that of the injured side was 29.26 ± 1.63°, ranging from 11.5° to 43.1°, with no statistical difference between the two ($P = 0.051$).

Radiographic outcomes

The measurement results for the length, height, width, Böhler angle, and Gissane angle of the healthy and injured calcaneus are shown in Table 2. The preoperative length, height, width, Böhler angle, and Gissane angle of the injured calcaneus significantly recovered compared to those preoperatively, and there was no reduction loss on comparison to the last follow-up (Fig. 6). According to the evaluation criteria for subtalar articular surface reduction proposed by Kurozumi et al. [18], one case (3.2%) was excellent, 25 cases (80.4%) were good, four cases (12.9%) were fair, and one case (3.2%) was poor. Fracture union was achieved in all the patients according to the last follow-up CT. Compared to the postoperative period, reduction loss of the articular surface was not found in the last follow-up CT (Table 3).

Table 2
Calcaneus radiographic (x-ray) data

Project	Healthy side	Preoperative	Postoperative	Last follow-up	F value	P value
Length (mm) [a]	73.14 ± 1.02	61.26 ± 1.36	73.19 ± 1.05	73.37 ± 1.13	27.147	<0.001
Height (mm) [b]	38.80 ± 0.75	34.38 ± 0.70	38.43 ± 0.79	38.09 ± 0.78	7.382	<0.001
Width (mm) [c]	43.50 ± 1.06	51.43 ± 1.08	43.01 ± 1.02	42.61 ± 1.08	15.796	<0.001
Böhler angle(°)[d]	30.76 ± 0.67	12.74 ± 1.49	30.40 ± 0.62	29.94 ± 0.54	59.387	<0.001
Gissane angle(°)[e]	120.76 ± 1.53	94.10 ± 2.06	120.10 ± 1.41	120.10 ± 1.66	92.575	<0.001

Note: ANOVA ([a]LSD test, postoperative with preoperative, P<0.001, and, postoperative with last follow-up, P = 0.909; [b]LSD test, postoperative with preoperative, P<0.001, and, postoperative with last follow-up, P = 0.752; [c]LSD test, postoperative with preoperative, P<0.001, and, postoperative with last follow-up, P = 0.785; [d]Tamhane's T2 test, postoperative with preoperative, P<0.001, and, postoperative with last follow-up, P = 0.994; [e]Tamhane's T2 test, postoperative with preoperative, P<0.001, and, postoperative with last follow-up, P = 0.195)

Table 3
Subtalar surface data measured by CT

Project	Preoperative	Postoperative	Last follow-up	F value	P value
Step (mm)[a]	4.10 ± 0.20	1.39 ± 0.12	1.01 ± 0.17	102.511	<0.001
Defect (mm)[b]	1.33 ± 0.20	0.28 ± 0.84	0.10 ± 0.05	308.090	<0.001
Angulation (°)[c]	7.44 ± 1.60	2.08 ± 0.90	0.26 ± 0.26	12.180	<0.001

Note: ANOVA ([a]Tamhane's T2 test, postoperative with preoperative, P<0.001, and, postoperative with last follow-up, P = 0.190; [b]Tamhane's T2 test, postoperative with preoperative, P<0.001, and, postoperative with last follow-up, P = 0.235; [c]Tamhane's T2 test, postoperative with preoperative, P = 0.016, and, postoperative with last follow-up, P = 0.165)

Complications

Postoperative CT of one patient revealed that the screw was too long and that the head broke through the calcaneocuboid articular surface. Screw replacement surgery was performed at 6 weeks after surgery before partial weight-bearing ambulation. This occurred in two patients with traumatic arthritis, including one patient at the 35-month follow-up after surgery with severe traumatic arthritis, poor subtalar joint surface reduction, and a fair AOFAS score. The other patient had mild traumatic arthritis at the 24-month follow-up after surgery, with good subtalar joint surface reduction and an excellent AOFAS score.

Discussion

After conservative treatment, patients with calcaneal fractures often suffer from malunion, traumatic arthritis, foot stiffness, pain, etc., which may result in limited walking, decreased living ability, and unemployment[19]. With the development of imaging technology, especially the CT-based intra-articular fracture classification of the calcaneus proposed by Sanders, doctors have realized the importance of reducing the shape of the calcaneus and subtalar articular surface through surgery[17]. An lateral extensile approach through the lateral calcaneus can achieve the desired reduction of a calcaneal fracture, but a 2-year follow-up study found that patients' pain and functional scores were equal to those of conservative treatment, while the incidence of surgery-related complications was as high as 19%[5]. The sinus tarsi approach is relatively minimally invasive and can reduce surgery-related complications, reduce the subtalar articular surface under direct vision, and achieve a similar reduction effect of the lateral extensile approach[20]. Zhuang et al. used the same locking plate to treat displaced intra-articular calcaneal fractures through extensile lateral approach and sinus tarsi approach, and this comparative study found that the walking Visual Analogue Scale (VAS) and AOFAS scores were identical in both groups[21]. Rammelt et al. performed open reduction of calcaneal fractures in 18 patients using the sinus tarsi approach, and 73.2% of the patients had limited subtalar joint mobility after surgery[10]. Studies on the sinus tarsi approach have found that this approach does not effectively improve the range of motion of the subtalar joint and the function of the hindfoot, which may be related to the stiffness of the subtalar joint caused by damage to the structures around the subtalar joint[10, 21]. Under normal circumstances, the subtalar joint has a limited range of motion and participates in foot and ankle movement along with the ankle joint and middle foot[22]. Perry et al. found that the subtalar joint mainly plays a role in alleviating the unbalanced force of the ankle joint during walking and plays a buffering role in hindfoot movement[23]. Thus, preserving as much motion as possible in the subtalar joint is essential for hindfoot function[24]. The technique of percutaneous poking reduction can avoid damage to the tissue around the subtalar joint and effectively preserves the range of motion of the subtalar joint [12–14]. In this study, we found that at the last follow-up, there was no statistical difference between the flexion and extension range of the ankle joint on the injured side and that on the healthy side. The average flexion and extension range of motion of the subtalar joint on the injured side was 29.27°, which could reach 88.6% of the range of motion of the healthy side. The average AOFAS score was 93.84 ± 7.92, and the excellent/good rate was 96.8%, which was better than that of previous open reduction and internal fixation operations[25].

At present, there is controversy regarding whether reduction of the calcaneal morphology or the subtalar articular surface should be prioritized. Dayton believed that calcaneus varus would lead to valgus compensatory stress in the middle foot and ankle, that a shortening calcaneus would increase the forward loading force on the ankle and weaken the pulling force of the posterior muscles, and that an increase in width would lead to a collision between the peroneus tendon and calcaneus, leading to a reduction in calcaneal morphology in the first place[2]. However, some studies have found that when the reduction of the subtalar articular surface is lost by 1 mm, the weight-bearing position will change, and traumatic arthritis will occur in the long term; therefore, Rammelt et al. [13] believe that the condition of the subtalar articular surface is the key factor in determining the prognosis. Kurozumi et al. targeted the reduction of the subtalar articular surface with step < 1 mm, defect < 5 mm, or angulation < 5° between fracture fragments, which was adopted by most researchers [9, 18, 20]. Closed reduction assisted by an external fixator not only adjusts the strength and direction of traction according to the reduction target but also temporarily maintains fixation, which has a unique advantage in reducing calcaneal morphology[6–8]; however, it is impossible to reduce the subtalar articular surface under direct vision, which may result in poor reduction of the posterior subtalar articular surface[7]. In some studies, arthroscopically assisted reduction of the subtalar articular surface achieved a similar reduction effect to open surgery; however, arthroscopically assisted reduction may not be suitable for surgeons who have not been trained in arthroscopic techniques[13, 14]. Radiological supervision of border projections is widely used as an indirect method to monitor subtalar articular surface reduction[26]. During the operation, the receiver was placed behind the ankle joint, the foot was in a neutral position, and the calf was rotated internally at 30–40°. The x-ray ball tube was aligned with the lateral malleolus, and the ball tube was rotated gradually towards the patient's head, so that reduction of the subtalar articular surface could be observed from anterior to posterior. Mimics V16.0 was used for preoperative planning, and bilateral external fixators were used for reverse traction during the operation to reduce the calcaneal morphology. The subtalar articular surface was reduced using a periosteal elevator under the radiological monitoring of border projections [27–29]. According to the fracture location, the insertion site of the periosteal elevator was selected, and the collapsed articular surface was elevated using a periosteal elevator through the external calcaneal wall channel. The anterior, middle, and posterior articular surfaces (including the sustentaculum tali) can be reduced through the medial calcaneal wall channel. The lateral compression fracture was reduced through the posterolateral side of the Achilles tendon, which was mainly adapted to the calcaneal fracture of Sanders IIa and IIIa. The fracture containing the middle part of the articular surface can be reduced through the bottom of the heel, which is mainly applicable to the calcaneal fracture of Sanders IIb and IIIb. Finally, percutaneous screws were used to support the subtalar articular surface. We found that the calcaneal morphology was reduced to normal through lateral and axial radiographs compared to the healthy side postoperatively. CT of the calcaneus showed that more than 83.6% of the subtalar articular surface was well reduced.

There are many surgical methods of closed reduction, including external fixator-assisted reduction[6–8], percutaneous balloon dilatation[30–32], and arthroscopy-assisted reduction[13, 14], and the percutaneous poking reduction is the basis of other technologies. Percutaneous poking reduction screw internal fixation is suitable for fresh calcaneal fractures of Sanders II–III and should be avoided in the following situations: Sander IV calcaneus fracture; old calcaneal fracture; subtalar articular inversion, for which assisted open reduction of tarsal sinus approach should be considered; For calcaneal nodules crushing or severe osteoporosis, traction reduction is limited, and which may lead to reduction failure. In this study, two patients underwent percutaneous poking reduction assisted by external fixators and changed the surgical procedure: one patient had a fracture involving the calcaneocuboid joint, which was fixed by limited incision and percutaneous insertion of a micro-locking plate; the other had obvious calcaneal swelling with blisters and blood bubbles on the 26 days after injury, for which intraoperative reduction through external fixator traction was attempted; however, this failed to achieve the desired reduction, and the patient finally underwent open reduction and internal fixation. Second, there is a risk of reduction loss after percutaneous screw fixation[16]. To avoid similar risks, Mimics V16.0 was used to simulate the reduction and fixation method to implement personalized treatment. We recommend that at least two screws be used for posterior subtalar articular surface fixation and that longer screws be used for sustentaculum tali fractures. To maintain the morphology of the calcaneus, at least two screws are used to fix each major fracture mass. Finally, ankle and subtalar joint rehabilitation training should be performed as soon as possible after surgery, and the time of weight-bearing activity should be determined strictly in accordance with fracture healing to prevent fracture reduction loss caused by premature weight-bearing. No loss of fracture reduction was found on comparison of radiographs and CT scans after surgery and at the last follow-up.

The most obvious advantages of percutaneous poking reduction assisted by external fixators and screw fixation over open surgery are the reduction in preoperative waiting time and hospital stay without the need for complete detumescence of the foot, the need not for intraoperative tourniquets, and less blood loss [25, 33]. However, radiation exposure is higher[33], requires precise preoperative design combined with imaging technology, and has high requirements for the position and direction of the implant and a long operative time. In this study, one patient underwent secondary screw replacement surgery at 6 weeks after surgery due to excessive screw length, and there is not the complications of wound infection, necrosis, or sural nerve injury. One patient was found to have severe subtalar traumatic arthritis on follow-up CT at 35 months postoperatively, and the AOFAS score was fair. In addition, one patient was found to have medium subtalar traumatic arthritis at the 24-month follow-up after surgery with an excellent AOFAS score.

This was a retrospective, cohort study. The clinical and imaging follow-up from 2 to 5 years showed that the treatment of the calcaneus with external fixator-assisted reduction and percutaneous screw fixation could meet the expected requirements of calcaneal reduction with fewer complications and a high rate of excellence in AOFAS score. However, there is a lack of controlled studies and long-term follow-up results comparing the extensile lateral approach and the tarsal sinus approach, and further controlled follow-up studies are needed to confirm the safety and effectiveness.

Conclusion

External fixator-assisted poking reduction and percutaneous screw fixation is a minimally invasive surgery for intra-articular calcaneal fractures and has a lower incidence of complications related to the operation. It can be achieved with calcaneal morphology and subtalar joint surface reduction and can reduce the impact on subtalar joint mobility, increasing the clinical effect. Long-term clinical effects can only be determined through further follow-up investigations.

Abbreviations

AOFAS
American Orthopaedic Foot and Ankle Society
CT
computed tomography

Declarations

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Availability of data and materials

Please contact the corresponding author for data requests.

Authors' contributions

JCW, HBL and JJT contributed to the follow-up and drafting of the article. JZ contributed to conception, design, and surgery. KJW and HC contributed to manuscript revision, English polish, reviewing. YJS and GLW contributed to data collection. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This retrospective study was approved and authorized by the Ethics Committee of the Fourth Medical Center of PLA General Hospital. The description of surgical technique, informed consent, surgical mechanism, expected therapeutic effect, potential risk, and iatrogenic injury was approved.

Consent for publication

For manuscripts that include details and images relating to individual persons, written informed consent for the publication of these details has been obtained from the patients.

Competing interests

The authors declare that they have no competing interests.

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Figures

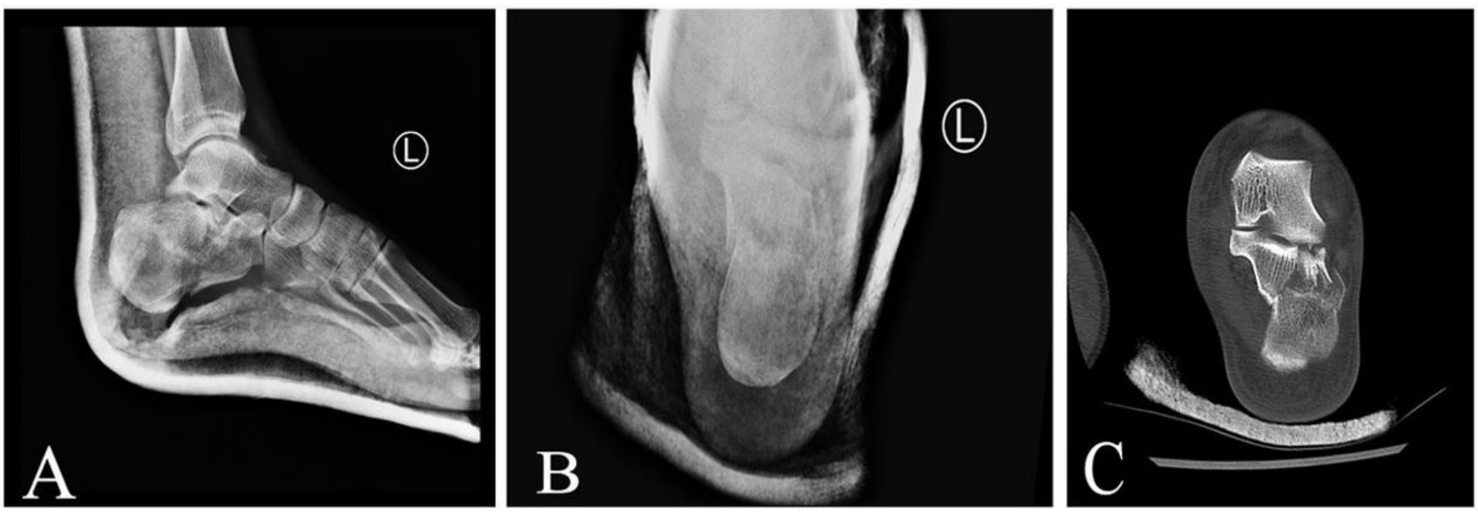

Figure 1

Preoperative x-ray and CT: A. X-ray lateral view showed that the Böhler Angle, Gissane Angle, height, and length of calcaneus were reduced. B. X-ray axial view showed that the calcaneus varus deformity and width increased. C. Coronal CT scan of the calcaneus showed a displaced intra-articular fracture, Sanders�ab.

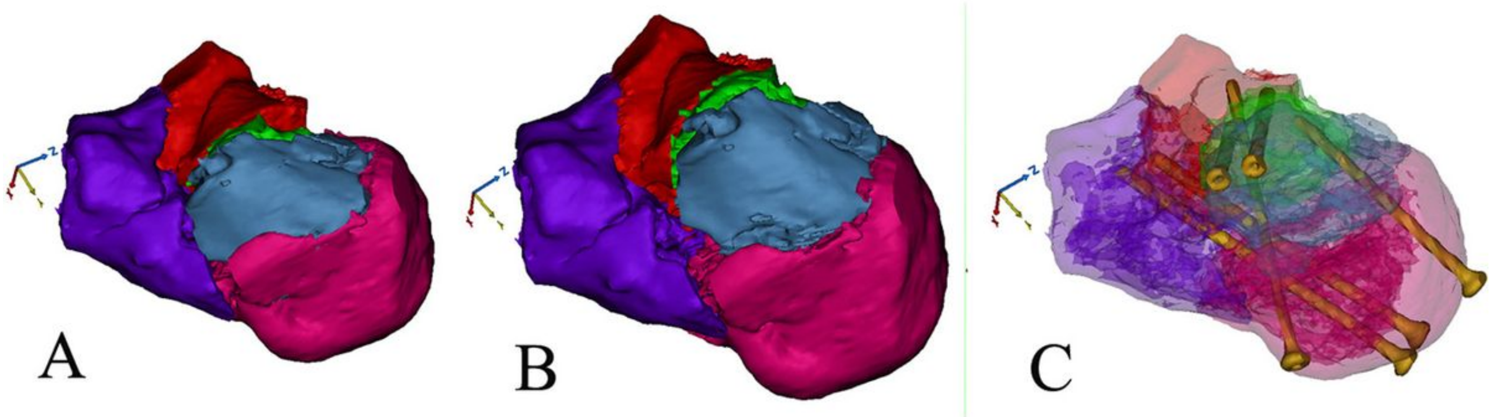

Figure 2

Preoperative design with Mimics V16.0: A. 3D CT reconstruction of the calcaneus before the simulated reduction; B. The main blocks of the calcaneal fracture were reduced using the system; C. Simulation of the implantation of cortical bone screws or cannulated screws.

Figure 3

Patient position and G-shaped fluoroscopy machine.

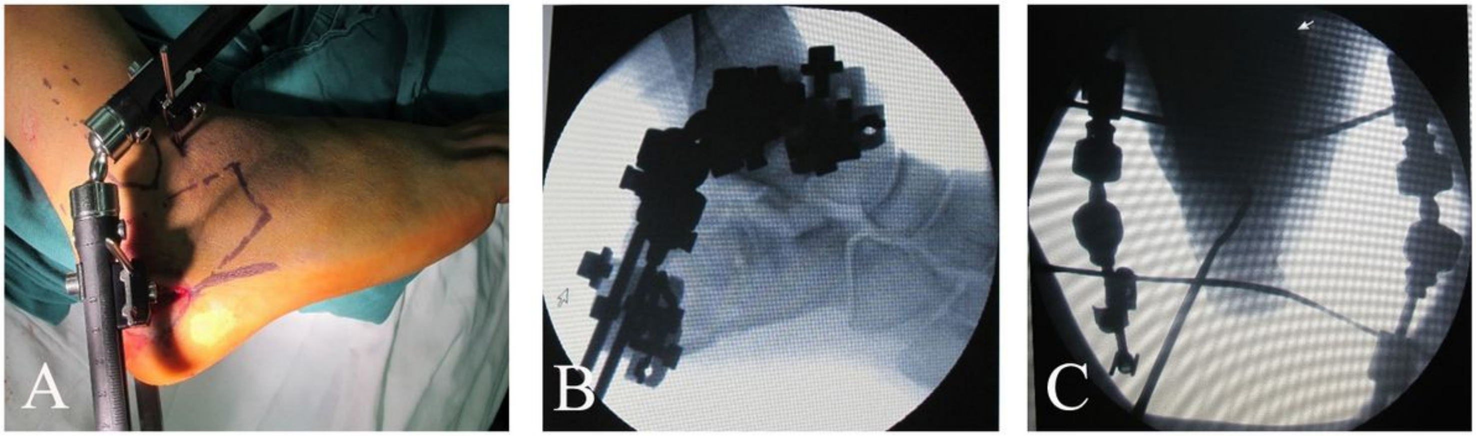

Figure 4

Calcaneus morphology reduction under external fixator traction: A. K-wire was implanted parallel to the talus and calcaneus, and the external fixator was installed; B–C. Reduction by traction with an external fixator; lateral and axial radiographs of the calcaneus showed that the Böhler angle, Gissane angle, height, length, width, and correction of varus angulation were reduced to normal.

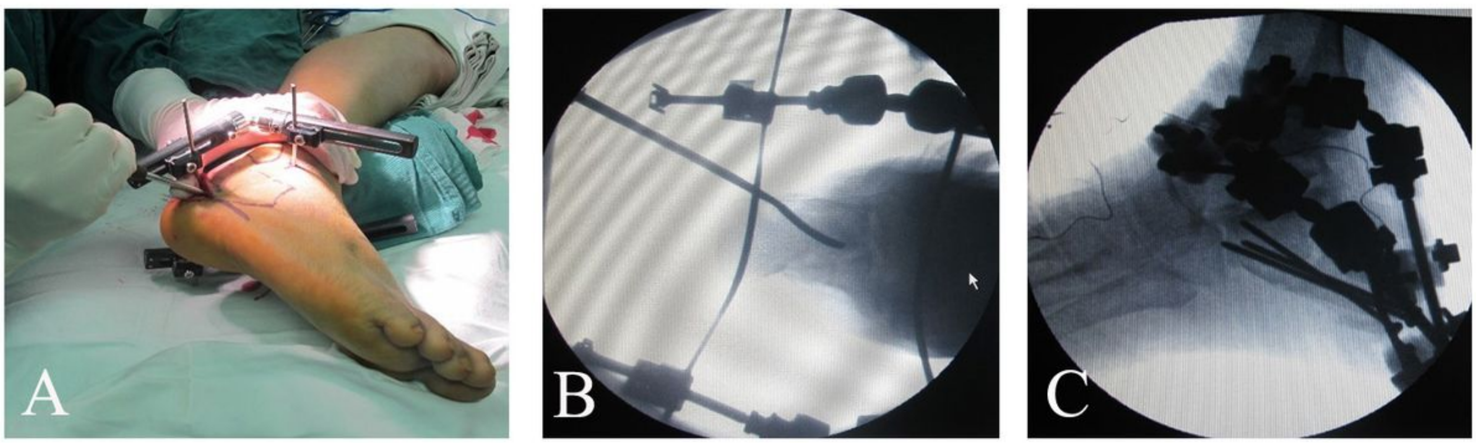

Figure 5

Reduce the subtalar articular surface and percutaneous screw fixation: A. Periosteal elevator inserted through the lateral wall fracture space; B. Axial radiographs of the calcaneus shows that the compressed subtalar articular surfaces was elevated by periosteal elevator; C. Border projections of the radiographs of the calcaneus showing reduction of the subtalar articular surface.

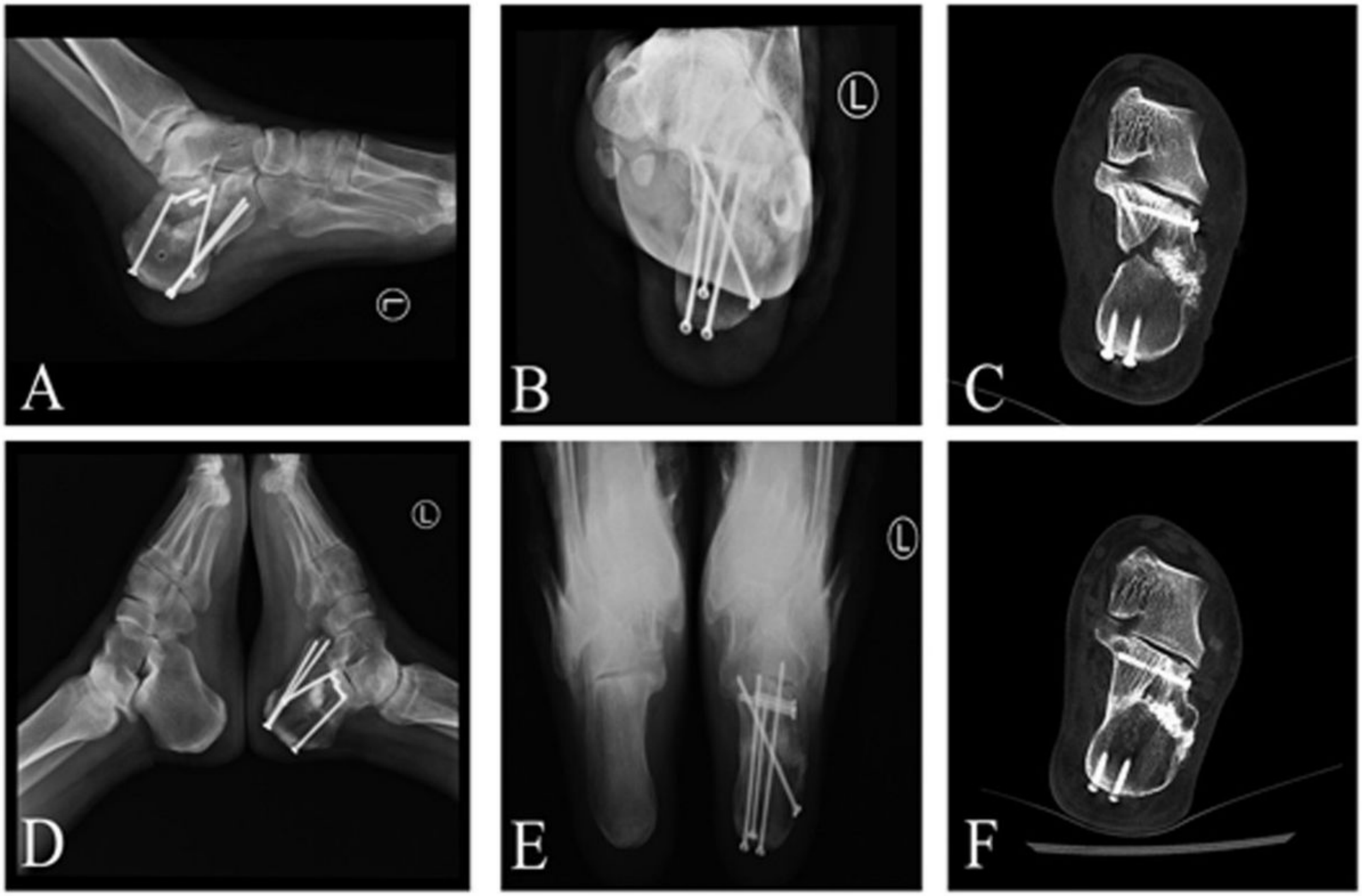

Figure 6

Lateral and axial radiographs and coronal CT of the calcaneus after surgery and at the last follow-up: A–C. Lateral (A) and axial (B) radiographs and coronal CT (C) of the calcaneus 6 months after surgery showing partial union of the calcaneus and no loss of fracture reduction. D–F. Lateral (D) and axial (E) radiographs and coronal CT (F) of the calcaneus 1 year after the operation showing complete union and no loss of fracture reduction.