CLINICAL ARTICLE

# Limb Reconstruction System Assisted Reduction and Internal Fixation for Intra-Articular Calcaneal Fractures: A New Application

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**Background:** Minimally invasive reduction and fixation of intra-articular calcaneal fractures poses great challenges for orthopaedic surgeons. The aim of the present study was to report the technical points, evaluate the efficacy of minimally invasive reduction and internal fixation assisted by the temporary limb reconstruction system (LRS) external fixator for intra-articular calcaneal fractures, and propose the indications of our protocol.

**Methods:** In this retrospective study, a series of 34 consecutive closed and displaced intra-articular calcaneal fractures involving the articular surface were treated by this technology between June 2016 and April 2018. X-ray and computed tomography (CT) scans were performed before and after surgery to measure Bohler's angle; the length, height, and width of the calcaneus; and the mechanical axis of the hindfoot. Postoperative complications were recorded. Imaging and clinical outcomes were comprehensively evaluated using the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot-ankle scoring system. After testing the normality of the data, Bohler's angle and the length of calcaneus were compared using the Wilcoxon signed-rank test. The height, width of the calcaneus, and the mechanical axis of the hindfoot were compared using the Paired-Samples *t*-test.

**Results:** Thirty-two fractures were followed up for an average of 20.66 months (from 12 to 32 months). All fractures achieved stable reduction and bony union. The articular surface was reduced and fixed with direct vision through the sinus tarsi incision. No failure of internal fixation or loss of reduction was detected during follow-up. There were no soft tissue complications. Bohler's angle; the length, height, and width of the calcaneus; and the mechanical axis of the hindfoot improved significantly. The AOFAS scores averaged 84.12 points; seven cases were rated excellent, 20 good, four fair, and one poor.

**Conclusions:** For intra-articular calcaneal fractures, minimally invasive surgery assisted with temporary LRS external fixation can reconstruct the calcaneal shape and the sub-talar articular surface. This simple surgical modality with limited complications may be helpful in the surgical treatment of most type II and III calcaneal fractures except comminuted fractures of the calcaneal tuberosity.

**Key words:** External Fixation; Internal Fixation; Intra-Articular Calcaneal Fracture; Limb Reconstruction System; Minimally Invasive

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## Introduction

Calcaneal fractures are the most common injury of the tarsal bones, accounting for 1%–2% of all fractures and about 75% of calcaneal fractures involve displacement of the subtalar joint.[1] Surgery is widely recognized as the most appropriate treatment for calcaneal fractures with intraarticular displacement.[2,3]

Lately, minimally invasive techniques, such as small incision and internal fixation, percutaneous reduction, and external fixation, have been used increasingly.[4,5] Although minimally invasive techniques for calcaneal fractures are effective in reducing soft tissue complications, they can lead to problems with intraoperative exposure and unstable reduction of fracture fragments, limiting their application for complicated calcaneal fractures (Sanders types III and IV).[6]

To resolve these problems, some scholars have proposed external fixators, such as nail-rod external fixators and circular external fixators, to treat calcaneal fractures.[7,8] External fixation can also reduce the complications related to traditional open reduction and internal fixation (ORIF). However, some researchers have discussed that during external fixation with a nail-rod system, it is difficult to effectively separate fracture fragments, fully expose the fracture line, or maintain the reduction of fracture fragments, while an external ring system might be too complex to treat calcaneal fractures.[1] In addition, long-term wear of an external fixator can lead to poor compliance by patients and complications such as pin infection, skin strain injury, joint stiffness, edema, traction pin rupture, and pain.[9–14]

Although external fixation has many complications, it still has the advantage of high biomechanical strength, especially the limb reconstruction system (LRS).[15] Therefore, we consider that the brief intraoperative use of the LRS system for minimally invasive reduction can not only take advantage of its high biomechanical strength but also avoid the complications of long-term wearing of external fixation.

Based on the available research concerning intraarticular calcaneal fractures, we treated 34 consecutive closed displaced intraarticular calcaneal fractures using minimally invasive reduction and internal fixation assisted with temporary LRS external fixator between June 2016 and April 2018. The purposes of the research are as follows: first, to report the technical points of using LRS to treat intra-articular calcaneal fractures in detail; second, to evaluate the efficacy of LRS assisted minimally invasive reduction and internal fixation in the treatment of intra-articular calcaneal fractures; and finally, to summarize the limitations and strengths of our protocol.

## Materials and Methods

From June 2016 to April 2018, 34 consecutive closed displaced intraarticular calcaneal fractures were treated using minimally invasive internal fixation assisted by temporary LRS external fixators (Orthofix Srl, Verona, Italy). This study was approved by the Ethics Committee of Nanfang Hospital, Southern Medical University (Approval No.NFEC-201901-K4-05). Inclusion criteria: We retrospectively collected the data of patients with closed Sanders type II, III, and IV intra-articular calcaneal fractures in the Department of Traumatology and Orthopaedics of Nanfang Hospital from June 2016 to April 2018. The surgical option is minimally invasive reduction assisted with LRS. Exclusion criteria: age <18 years, follow-up time <12 months, open calcaneal fractures, pathological fractures, and comminuted fractures of the calcaneal tuberosity.

### *Instrument Preparation*

The LRS fixator consists of monolateral frames of different sizes, which are usually used for upper and lower limb fractures, and we selected the two smallest LRS external fixators (lower limb fixator: 35 × 230 mm, upper limb fixator: 22 × 150 mm) for use in calcaneal fractures (Figure 1). In all patients, first, a temporary LRS external fixator was used to assist in the reduction of the fracture fragments, and then a sinus tarsi incision was made to fix the fracture fragments, using either cannulated screws or plates and screws, and then the external fixator was removed after ORIF.

### *Preoperative Preparation*

Patients were treated initially using bed rest, elevation, ice packing, compressive bandaging, and anti-swelling medicine after admission until the skin wrinkles of the foot became visible.

### *Surgical Techniques*

#### *Position*

The patient was placed in the prone position. The ankle joint of the affected limb was supported in a high position using a cushion, with the planta pedis parallel with the edge of the bed (Figure 2).

#### *Implanting the Three External Fixation Pins*

The first pin (calcaneus pin) was implanted from the medial to lateral in the heel, guided by C-arm fluoroscopy to ensure

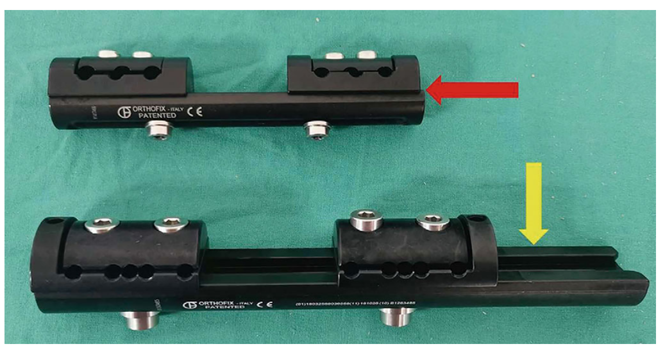

**FIGURE 1** The lower and upper limb fixators (Limb Reconstruction System, LRS. Yellow arrow: lower limb fixator; Red arrow: upper limb fixator).

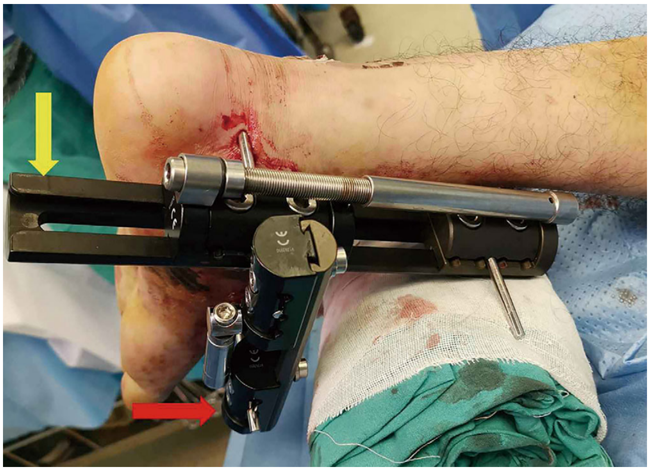

**FIGURE 2** The patient is placed in the prone position (Yellow arrow: lower limb fixator; Red arrow: upper limb fixator).

that the pin was implanted into the posterosuperior cortical bone of the posterior calcaneal tuberosity. The preoperative CT scan and calcaneus axial radiography were used to judge whether there is varus or valgus in the calcaneus. If there was varus, according to the varus angle, the calcaneus pin was slightly inclined forward along the calcaneal longitudinal axis; if there was no obvious varus, the calcaneus pin was adapted perpendicular to the long axis of the calcaneus. The calcaneus pin was screwed into the calcaneus until it penetrated the lateral cortical bone. The second pin (tibia pin) was inserted into the anterior aspect of the tibia at 10 cm above the articular surface of the ankle. The pin should penetrate the lateral cortex of the tibia. The third pin (Cuneiform pin) should penetrate the medial, middle, and lateral cuneiform bones from inside to outside (Figure 3A, B).

*Installation of the LRS External Fixator*

The first LRS external fixator (lower limb fixator) was installed between the calcaneal pin and the tibial pin, which should be placed as close to the inner skin of the calcaneus as possible to ensure more traction (Figure 3C). The second LRS external fixator (upper limb fixator) was installed between the calcaneal pin and the Cuneiform pin (Figure 3D). The three external fixation pins should be inserted into the center clamp groove of each LRS external fixator.

*Restoring the Height, Length, and Width of the Calcaneus Using an LRS External Fixator*

Two compression distraction units (C/D units) were installed on two LRS external fixators. First, the C/D unit on the LRS external fixator installed on the calcaneus and tibia was usually distracted by no more than 2.5 cm in our experience. At this time, partial reduction and elevation of the collapsed posterior articular surface could be monitored on a lateral radiograph. If there was an incarceration of fracture fragments, the space below the posterior talus articular surface would be significantly widened. Then, the C/D unit on the second LRS external fixator was usually distracted by no more than 1.5 cm to restore the length of the calcaneus, and the distraction was stopped after a significantly widening of the space of the calcaneocuboid joint was observed. Restoration of the calcaneus length could be monitored in the foot axial radiograph, and the lateral wall bulging and calcaneus varus could be corrected (Figure 3E). Next, all the clamps on the LRS external fixators should be tightened and fixed using a C/D unit.

*ORIF with a Sinus Tarsi Incision*

The procedure of ORIF via a sinus tarsi incision had been mentioned by other authors.[16] A 5-cm horizontal incision was made. Extending from the base of the fourth metatarsal to the tip of the fibula, over the sinus tarsi. Carefully separated and preserved peroneal tendons and sural nerve, which runed at the posterior part of the incision. After traction with the lower limb LRS external fixator, a significantly increased space in the subtalar joint could benefit the recovery of Bohler's angle and the sub-talar articular surface (Figure 4A). Then, we separated the outer cortex from the soft tissue using a stripper. Prying and raising the fragments of posterior calcaneal tuberosity to restore the integrity of the calcaneal height and subtalar articular surface, and a 2.5 mm Kirschner wire penetrated the subtalar joint from posterior tuberosity for temporary fixation. One or two cannulated screws (5.5 mm, Tianjin Zhengtian Medical instrument Co. Ltd) were inserted from the posterior calcaneal tuberosity to the anteroinferior of calcaneus to prevent varus of the calcaneus. The peroneal tendon sheath was protected during the operation. The sub-talar articular surface was reconstructed using a minimally invasive calcaneus plate through the same approach to achieve more rigid fixation (Figure 4B). Most of the time, bone graft was not necessary. In addition, calcaneus axial radiography and 10°–40° Broden X-ray films were taken to ensure satisfactory fracture reduction and internal fixation placement. The 2.5 mm Kirschner wire was removed. Subcutaneous tissue and skin were sutured with 3/0 Vicryl and 3/0 Proline. The prone position was used for placing the axial screw and obtaining axial view radiographs. The LRS external fixators were then removed.

***Postoperative Treatment***

The patients were given NSAIDs drugs for pain relief within 1 week after the operation. Localized ice compression was continued for 3 days, and continuous pressure bandaging was applied. The sutures were removed after 12–14 days. During hospitalization, the patients were instructed to do ankle pump exercises. Weight bearing was started gradually according to the situation of fracture healing as evaluated by X-ray re-examination after 8 weeks.

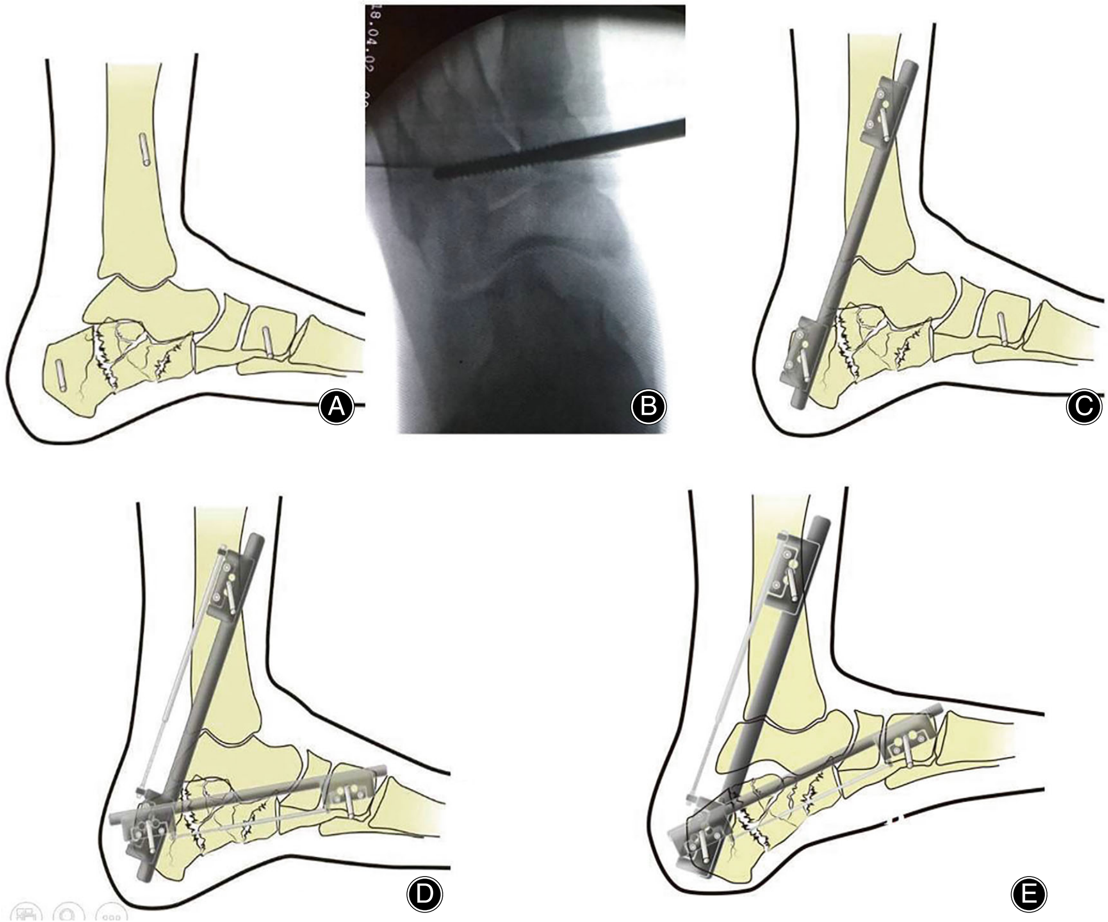


**FIGURE 3** (A) Three external fixation pins are implanted into the calcaneus, tibia, and cuneiform. (B) Anteroposterior radiograph shows that the pin is implanted across the medial, intermediate, and lateral cuneiform from medial side. (C) The first LRS external fixator (lower limb fixator) is installed between the calcaneal pin and the tibial pin and the external fixator should be placed close to the inner skin of the calcaneus; (D) The second external fixator (upper limb fixator) is installed between the calcaneal pin and the cuneiform pin; (E) Two compression distraction units are installed on two LRS external fixators and lengthened, then the height and length of the calcaneus are recovered significantly.

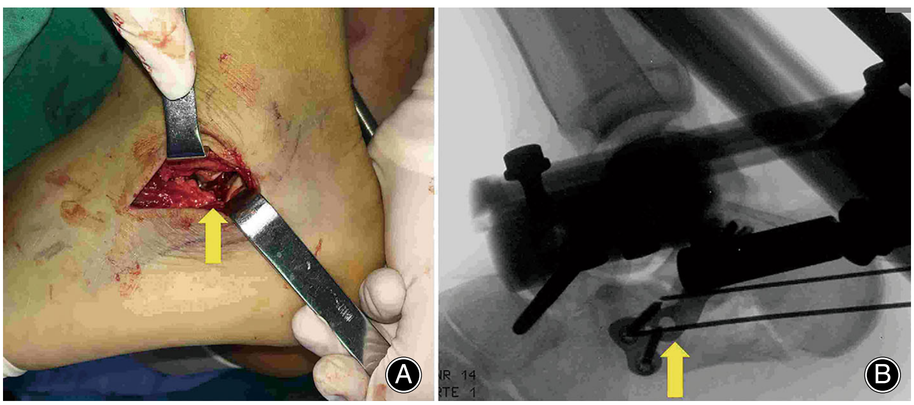


**FIGURE 4** (A) a significantly increased space in the subtalar joint could benefit the recovery of Bohler's angle and the sub-talar articular surface (yellow arrow). (B) the sub-talar articular surface was reconstructed using a minimally invasive calcaneus plate (yellow arrow).

*Assessment*

X-ray were performed before and after surgery to measure Bohler's angle; the length, height, and width of the calcaneus; and the mechanical axis of the hindfoot. Moreover, a preoperative CT scan was performed for Sanders classification of the calcaneal fractures and postoperative CT for re-examination of subtalar joint reduction. All our images and digital measurements are obtained through the Picture

Archiving and Communication System (PACS). The outcomes were evaluated comprehensively using the American Orthopaedic Foot and Ankle Society (AOFAS) scores (excellent, 90–100; good, 80–89; fair, 70–79; poor <70).[17] Postoperative complications were recorded.

Patients were evaluated using standard X-ray films every 4 weeks in the first 6 months after surgery and every 3 months thereafter. AOFAS scores were performed 1 year after surgery. Patients were then followed up every 6 months and AOFAS scores were recorded until patients were lost to follow-up. The AOFAS score at the last follow-up was recorded, and complications were recorded during follow-up.

### *Statistical Analysis*

After testing the normality of data, the preoperative and postoperative Bohler's angle and the length of calcaneus were compared using the Wilcoxon signed-rank test. The height, width of the calcaneus, and the mechanical axis of the hindfoot were compared using the Paired-Samples $T$ test. $p < 0.05$ was considered statistically significant. IBM SPSS Statistics 20 software was used for the analysis (IBM Corp., Armonk, NY, USA).

## Results

### *Patients Data*

Among the 34 fractures, 32 were available for follow-up. Two patients were lost to follow-up because they came back to hometown. There were 28 males and four females aged from 21 to 61 years (average, 43.56 years). According to the Sanders classification, 17 cases were classified as type II, nine as type III, and six as type IV. The left foot was affected in 18 cases, and the right foot was affected in 14 cases. Their follow-up duration averaged 20.66 months (12–32 months).

### *Primary Outcomes*

Surgery was performed at an average of 6.47 days after admission (the skin wrinkles of the foot became visible again). The operation time averaged 81.68 min (63–121 min). All the fractures achieved bony union with no postoperative soft tissue necrosis or deep infection. The AOFAS ankle/hindfoot score averaged 84.12 at the last follow-up, giving seven excellent, 20 good, four fair, and one poor case. There were significant improvements in the mean Bohler's angle (preoperative 8.76° [from −26.05° to 40.00°] vs. 26.88° [from −6.31° to 46.50°]), the mean height of the


**FIGURE 5** The patient was male, 42 years old, and had a left calcaneal fracture of Sanders type IIIB (A–C). A temporary LRS external fixator combined with a sinus tarsal incision was performed on the 7th day after injury. The X-ray and CT scan were performed after surgery, and the calcaneal height, width, and articular surface were almost recovered (D–F).

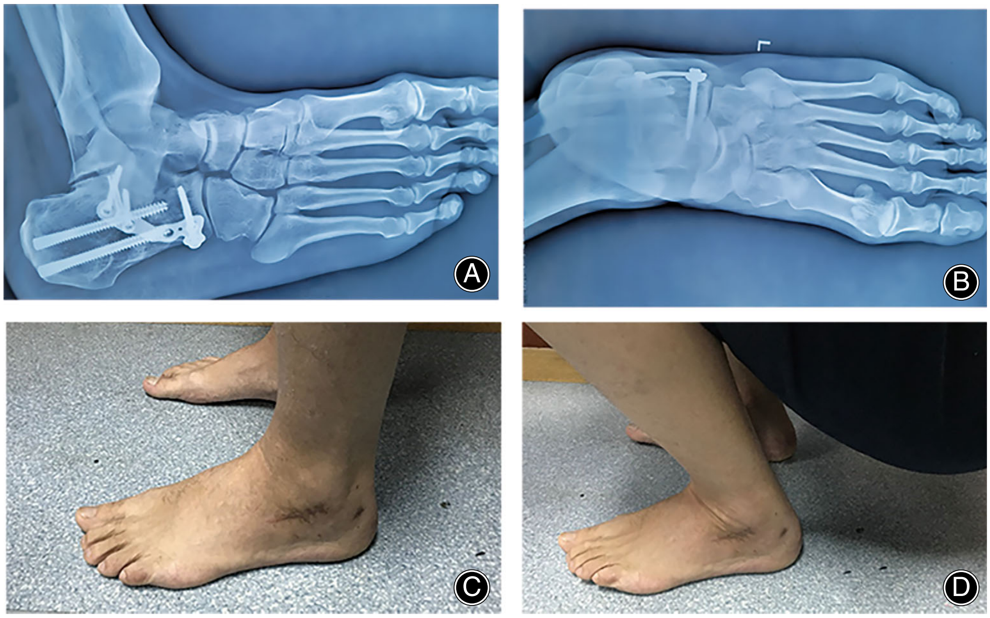

**FIGURE 6** One year later, the X-ray of the patient's calcaneus (A, B). The ankle joint and sub-talar function had recovered well (C, D).

calcaneus (preoperative 40.69 mm vs. postoperative 47.22 mm), the mean length of the calcaneus (preoperative 76.60 mm vs. postoperative 89.95 mm), the mean width of the calcaneus (preoperative 47.10 mm vs. postoperative 39.99 mm), and the mean valgus angle of the hindfoot (preoperative 4.21° vs. postoperative 5.44°) (all $p < 0.05$).

### *Typical Case*

The patient was male, 42 years old, and had a left calcaneal fracture of Sanders type III B (Figure 5A–C). A temporary LRS external fixator combined with a sinus tarsal incision was performed on the 7th day after injury. The X-ray and CT scan were performed after surgery, and the calcaneal height, width, and articular surface were almost recovered (Figure 5D–F). One year later, the calcaneal fracture had been healed completely (Figure 6A, B). The ankle joint and sub-talar function had recovered well (Figure 6C, D).

### *Complications*

No failure of internal fixation or loss of reduction was detected during follow-up. Twenty patients achieved a normal or slightly restricted range of motion of the sub-talar joint after surgery, but the symptoms were relieved after manual massage and low-frequency electrical stimulation rehabilitation treatment. And one patient walked supported by crutches for 6 months post-surgery because of foot pain. Localized short-term osteoporosis was observed in six patients, which responded to symptomatic therapy 5 months later. One patient experienced numbness on the soles that did not affect their gait or walking function. None of the patients underwent secondary surgery in our hospital (Tables 1 and 2).

## Discussion

Minimally invasive surgery assisted temporary LRS external fixation is suitable for intra-articular calcaneal fractures without comminuted posterior tubercle, which not only can reconstruct the shape of the calcaneus and the subtalar articular surface but also there are no soft tissue complications.

**TABLE 1 Statistical description of the case series ($N = 32$)**

| Variable | Mean ± SD (minimum, maximum) |
|---|---|
| Age, years | 43.78 ± 9.83 (21, 60) |
| Sex | |
| Female | 8 |
| Male | 38 |
| Side | |
| Left | 24 |
| Right | 22 |
| Sanders classification | |
| II | 24 |
| III | 14 |
| IV | 8 |
| Operative time, min | 80.89 ± 15.23 (63, 121) |
| AOFAS score | 83.85 ± 7.80 (61, 100) |
| Sanders II | 87.67 ± 4.49 (77, 100) |
| Sanders III | 84.00 ± 4.74 (75, 90) |
| Sanders IV | 72.13 ± 8.72 (61, 87) |
| Time from injury to surgery, d | 9.50 ± 2.40 (4, 14) |
| Injury to admission, d | 2.93 ± 1.34 (1, 7) |
| Admission to surgery, d | 6.56 ± 1.46 (3,1 0) |
| Time of follow-up, months | 20.93 ± 5.62 (12, 32) |
| Postoperative complications, *n* | 6 |
| Osteoporosis | 5 |
| Numbness | 1 |
| Tissue necrosis or deep infection | 0 |

Abbreviation: AOFAS, American Orthopaedic Foot and Ankle Society.

**TABLE 2 Comparison of preoperative to postoperative outcomes ($N = 32$ calcaneal fractures)**

| Variable | Preoperative (mean ± SD) | Postoperative (mean ± SD) | Test statistics | *p*-value* |
|---|---|---|---|---|
| Calcaneal width, mm | 47.10 ± 5.75 | 39.99 ± 5.48 | −8.146 | <0.001 |
| Calcaneal height, mm | 40.69 ± 5.47 | 47.22 ± 3.73 | 6.183 | <0.001 |
| Calcaneal length, mm | 76.60 ± 6.94 | 79.95 ± 5.61 | −3.665 | <0.001 |
| Bohler's angle, ° | 8.76 ± 16.15 | 26.88 ± 8.33 | −3.983 | <0.001 |
| Alignment, ° | 4.21 ± 0.51 | 5.44 ± 0.53 | 8.627 | <0.001 |

*Note*: Other outcomes were analyzed using a Paired-Samples T test; Abbreviation: SD, Standard Deviation.; * Signed ranks test: Calcaneal length, mm, Bohler's angle (°).

### *The Technical Points of Using LRS Intraoperatively*

The LRS external fixation used in our surgical procedure had been used for extension or reconstruction of upper and lower limb fractures.[18–20] We integrated LRS external fixation into our surgical protocol as a temporary aid to intraarticular calcaneal fracture surgery because of the following advantages. First, it could provide a powerful traction force to expose the subtalar joint. LRS external fixation combined with the sinus tarsi approach could fully expose the subtalar articular surface and provide enough space to reduce the fractures. Second, the rigid LRS fixation placed on the medial side of the calcaneus could effectively prevent reduction loss and correct calcaneus varus after fracture reduction. Third, the two C/D units of the LRS external fixator might allow dynamic axial traction or compression to perfect the reduction. After completed installation of LRS external fixation, traction could be exerted by adjusting the C/D units without manual pulling, as described by Kissel,[21] and minute traction could be fine-tuned according to the intraoperative situation. Moreover, the 5 mm pin in the LRS external fixator inserted into the calcaneal tuberosity might play a role in stabilizing fracture fragments to maintain intraoperative fracture reduction. The significant benefits brought by temporary LRS external fixation in the effective maintenance of fracture fragments were the reduced use of fluoroscopy (20 times on average) and consequently less total operation time (81.68 min on average). This led to a lower rate of surgical complications, according to the very limited data reported.[22,23] Finally, the LRS external fixation in our surgical protocol was used only intraoperatively and was removed by the end of surgery; therefore, complications were caused by long-term wearing of the external fixator, such as pin tract infection, skin strain injury, joint stiffness, edema, traction needle rupture, pain.[9–14]

### *Evaluate the Efficacy of LRS Assisted Minimally Invasive Reduction*

Other methods of external fixation have also been reported. Farrell et al.[24] used temporary external fixation followed by minimally invasive internal fixation to treat 11 calcaneal fractures for which early emergency external fixation was performed to help restore normal calcaneal structure and the corresponding soft tissue envelope. The external fixation, used for an average of 4.8 days, was removed before definitive plate fixation via the sinus tarsi approach. Our surgical scheme was different from that of Farrell et al. in several ways: First, their external and internal fixation was carried out in two separate operations, while ours was performed in one single operation. This was because our swelling reduction scheme was different from theirs. Similar to the report by Fu et al.,[9] in our treatment protocol, the patients were initially treated with elevation, ice packing, compressive bandaging, and anti-swelling medication after admission. Our surgical treatment was not carried out until the swelling of the foot subsided significantly (an average of 6.47 days after admission), when the skin wrinkles of the foot were visible. Second, our external fixation was a temporary means that was mainly used to assist definitive plating and was removed by the end of surgery, while in Farrell et al.'s method, external fixation was worn for days before the definitive plating. Moreover, although it is not known whether their temporary external fixators were recycled or not, our LRS external fixators were recycled the same as other surgical instruments after thorough disinfection. Our swelling reduction time was longer than theirs; however, in our technique, the time that the patients wore external fixation was much shorter than theirs (81.68 min vs. 4.8 days on average). Taken together, the evidence indicates that our treatment protocol might be more convenient and less expensive for patients. Early reduction and internal fixation surgery for calcaneal fracture might increase the chance of soft tissue complications[25]; however, our surgical practice and that of Farrell et al.[24] showed no such postoperative complications.

Fu et al.[9] argued for the use of external fixation in conjunction with open reduction and limited internal fixation as a single-stage via a lateral L-shaped extended incision. Their external fixator was retained together with limited internal fixation for 3 months postoperatively. Compared with their reported data, our treatment protocol achieved similar improvements; however, they reported 13 cases (27%) of postoperative complications (superficial pin tract infection in seven cases, superficial wound edge necrosis in four cases, and deep wound infection in two cases), and we did not observe any postoperative soft tissue complications. We believe that the wound edge necrosis and deep wound infection reported by Fu et al. might be related to the lateral L-shaped extended incision. Compared with the methods of tarsal sinus approach (70.52 ± 13.16) and lateral L-shaped incision approach (55.24 ± 12.2) reported by Du,[26] the operation time (80.89 ± 15.23) are truly prolonged in our study.

Our study did not show much difference in postoperative calcaneal length (79.95 ± 5.61), width (39.99 ± 5.48), height (47.22 ± 3.73), and Böhler's angle (26.88 ± 8.33) compared to those reported by Yeo.[27] However, we have the advantage that postoperative complications are greatly reduced because of satisfactory reduction and mini incision.

For Sanders type IV calcaneal fracture, Lin et al.[28] treated 29 patients via a sinus tarsi approach and 40 patients via the extensile lateral approach. The average postoperative AOFAS score of the sinus tarsi incision group was 75.45, and that of extensile lateral approach was 72.44. In the sinus tarsi incision group, five patients had soft tissue complications. In the extensile lateral approach group, 16 patients had soft tissue complications. In our study, the AOFAS score of the patients with Sanders type IV calcaneal fracture was 73.33; however, our study used external fixation to assist minimally invasive internal fixation. No patients experienced soft tissue complications, such as wound infection and necrosis.

### Surgical Tips

There are two surgical tips. First, the prone position used in our surgery is crucial, particularly for Sanders type III and type IV fractures. Compared with other positions, the prone position might, at least partially, compensate for the poor light transmission caused by the LRS external fixator for intraoperative fluoroscopy. Additionally, it might facilitate insertion of the longitudinal fixation screw from the posterior calcaneal tuberosity to the anteroinferior of the posterior calcaneus, and thus enable correction of the articular surface and varus according to the intraoperative calcaneal axial radiography. Secondly, to avoid iatrogenic fracture, the distraction strength should be limited by compression distraction units (C/D units). The C/D unit on the LRS external fixator installed on the calcaneus and tibia was usually distracted by no more than 2.5 cm in our experience. Then, the C/D unit on the second LRS external fixator was usually distracted by no more than 1.5 cm.

### Limitations and Strengths

Our surgical protocol has inherent shortcomings. First, because of the interference of LRS external fixator, the quality of intraoperative lateral X-rays was poor so that multiple Broden positions should be taken intraoperatively to assess the reduction of the posterior articular surface. Second, our method might not be appropriate for severely comminuted fractures of the posterior calcaneal tuberosity, because the pins of the LRS external fixator cannot be installed. Third, for Sanders type IV, we acknowledged that this surgery did not do as well as a full ORIF, because the anatomic reduction of Bohler's angle was tough to achieve. The most significant limitations of our retrospective observation were the lack of a control group, the small number of cases, and limited follow-up time. Our surgical protocol requires validation using more high-quality clinical studies, and modifications and comments from our peers.

Despite the recognized limitations, this study has some advantages. First, using LRS intraoperatively can fully expose the subtalar articular surface and provide enough space to reduce fractures. Second, our surgical protocol basically avoids soft tissue complications caused by external fixation and ORIF. Finally, our surgical protocol reduces the patient's financial pressure because our LRS external fixators were recycled the same as other surgical instruments after thorough disinfection.

### Conclusion

Although our method may not be suitable for severely comminuted posterior calcaneal tuberosity fractures and the quality of intraoperative lateral radiographs is poor, this surgical protocol, comprising minimally invasive internal fixation assisted by temporary LRS external fixation, provides an alternative method for surgeons. It promises good results by restoring the calcaneal height, length, and width, while avoiding the complications often associated with ORIF and external fixation. This simple surgical modality may be helpful in the surgical treatment of most Sanders type II and III calcaneal fractures except comminuted fractures of the calcaneal tuberosity.

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## Author Contributions

Guiyong Jiang was involved in all the patients' operations and wrote the first manuscript. Jie Li collected the medical records and literature. Xiaolong Zhang collected the follow-up data and literature. Other people also made important contributions to this study. Hua Liao did the main data analysis. Jijie Hu was responsible for all the patients' surgeries, study design, and manuscript correction. All authors read and approved the final manuscript.

## Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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## Ethical Approval

This study was approved by the Ethics Committee of Nanfang Hospital, Southern Medical University (NFEC-201901-K4-05).

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