CLINICAL ARTICLE

Multiple Reconstructive Osteotomy Treating Malunited Calcaneal Fractures Without Subtalar Joint Fusion

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Objective: Various surgical techniques have been reported in treating calcaneal malunions over the decades, while the operations on single plane were accompanied by respective limitations. The purpose of this study is to evaluate the efficacy of a novel multiple reconstructive osteotomy for treating malunited calcaneal fractures without subtalar joint fusion.

Methods: From March 12, 2010, to August 17, 2017, 10 patients (10 feet) with malunited calcaneal fractures were treated with multiple reconstructive osteotomy with subtalar joint-preserving operations. All patients were treated with a corrective osteotomy, joint realignment, soft tissue balancing, and secondary internal fixation at a mean of 5.6 ± 2.41 months since the initial injury. With the utilization of the multiple reconstructive osteotomy, the posterior facet was restored to preserve the subtalar joint. All patients were evaluated clinically and radiographically at a mean follow-up of 3.04 ± 1.21 years.

Results: All patients were subjectively satisfied with the treatment. The average time to union was 12.2 ± 1.11 weeks. The American Orthopedic Foot and Ankle (AOFAS) ankle and hind foot score was 86.3 ± 4.45 ($t = 27.64$, $P < 0.0001$, paired *t*-test), which was significantly higher than the preoperative assessment. Postoperative radiographic assessment revealed great improvement in Böhler's angle (from 25.4° to 86.3°), talocalcaneal height (65.15–72.68 mm) and Calcaneus-talus angle (from 34.46° to 39.7°). One patient had mild discomfort after a 1-h brisk walk. One patient was suspected to have early posttraumatic arthritis of the subtalar joint based upon radiographic evidence during the follow-up, but the patients could walk normally for a long time without pain.

Conclusion: Multiple reconstructive osteotomy is an effective way to restore the calcaneal morphology and preserve the subtalar joint for selected calcaneal malunion.

Key words: Calcaneal malunion; Calcaneus; Correction; Fracture; Osteotomy; Subtalar joint preservation

Introduction

Pain, limping, and deformity are the most common complications following calcaneal malunions, which result from untreated/inappropriately treated calcaneal fractures.[1] Patients often suffer from both physiological and psychological stress, accompanied by financial strain

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because of the inability to return to their former occupation. However, the treatment of calcaneal malunion remains a challenge in the clinic.

Over the past decades, various corrective osteotomies with/without fusion of the subtalar joint have been reported. Depending on the type of deformity and the injury mechanism, many authors have advocated different reconstructive strategies, including lateral wall exostectomy (for treating patients with impingement in the subfibula region resulting from the widened lateral wall),[2] lateral wedge osteotomy, including lateral closed wedge osteotomy (Dwyer osteotomy)[3] and lateral opening wedge osteotomy (for correcting the varus/valgus deformity),[4] Romash osteotomy (refreshing the malunited fracture along the original fracture line to achieve anatomical reconstruction of the calcaneus),[5] In recent years, modified procedures based on classic osteotomies have also been reported with satisfactory results.[6–8] Current studies have confirmed that calcaneal corrective osteotomy is an effective way to treat calcaneal malunions to alleviate pain and restore the normal morphology of the calcaneus. Although calcaneal malunion has raised attention in recent years, the specific issues are still confusing to surgeons, including how to choose the proper osteotomy procedure, whether fusion or subtalar joint preservation.

With the aforementioned methods usually being presented to deal with specific deformities and symptoms, the osteotomy performed on a single plane could hardly resolve problems in multiple planes. For instance, although lateral wall exostectomy and lateral wedge osteotomy were able to narrow the width of the calcaneus and correct the deformity in the axial view, respectively, they have little significance in restoring the calcaneal height. In addition, such extra-articular osteotomies seemed to be helpless in delaying the process of arthritis of the subtalar joint. Therefore, subtalar arthrodesis is often the choice to relieve the symptoms of posttraumatic arthritis, but the procedure frequently leaves additional residual complaints.[9–11] The subtalar joint plays an important role in the function of the hind foot. Shown in a cadaver study by Savory *et al.*,[12] the motion of the talonavicular joint decreased significantly after subtalar arthrodesis, including a 56% decrease in dorsiflexion and plantar flexion and a 70% decrease in inversion and eversion. The normal anatomical structure of the subtalar joint also allows a 3-dimensional motion of the distal foot.[13] In addition, the pronation and supination of the subtalar joint during the gait cycle is of great significance for adapting to ground surface and structural abnormalities. Because of deeper awareness of the importance of the subtalar joint, preserving the motion and congruence of the subtalar joint has become a concern in recent studies seeking an ideal procedure for the treatment of calcaneal malunion.

Considering these issues, a retrospective study was conducted over the past 7 years. Ten patients who suffered from malunited calcaneal fractures without/with mild subtalar arthritis were carefully selected. A multiple calcaneal osteotomy without subtalar joint fusion was performed on those patients with a mean time of follow-up of 3.4 years for efficacy assessment. The significance of this study is to present a multiple joint-preserving reconstructive osteotomy, which aims to restore the whole structure and function of the hindfoot in treating calcaneal malunions. We hypothesize that with osteotomies in multiple planes and preservation of the subtalar joint, not only a normal calcaneal morphology but also a preferable function could be gained. The purpose of this study was to: (i) present a novel surgical technique performed on multiple planes; (ii) present the procedure preserving the subtalar joint based on the condition of cartilage of the subtalar joint; and (iii) report the clinical outcomes of the method, providing new insight to treat malunion of the calcaneus through one surgery.

Patients and Method

Ethic Approval

This study was a retrospective survey conducted at our hospital, a tertiary medical center in Southern China. The requirement for written informed consent was waived, owing to the observational study design. Personal information was anonymized prior to data analysis. The study protocol was approved by the medical ethical committee of Southern Medical University Nanfang hospital (No. NFEC-2021-085).

Participants

From March 12, 2010, to August 17, 2017, 127 calcaneal malunions in 120 patients were surgically treated in our department. All patients with calcaneal fractures had been initially managed at other hospitals. The initial treatments included conservative treatments, which were performed on 38 feet with Sanders type I calcaneal fractures and 16 feet with Sanders type II fractures; surgical treatments of open reduction and internal fixation (ORIF), which were conducted on 36 feet with Sanders type II fractures and 19 with Sanders type III fractures; and subtalar joint fusion, which was performed on three feet with Sanders type III fractures and all Sanders type IV calcaneal fractures of 15 feet. Among them, patients with type I, II and III calcaneal malunions according to the Sanders calcaneal malunion classification were selected to receive a multiple reconstructive osteotomy with subtalar joint-preserving operation. Beforehand, the articular cartilage of the calcaneal posterior facet was expected to be without or with mild osteoarthritis through preoperative radiographs, CT, and intraoperative visualization.

The inclusion criteria were as follows: (i) patients were definitely diagnosed with Sander I, II and III calcaneal malunions according to the Sanders calcaneal malunion classification; (ii) the period from the initial injury to reconstructive surgery was at least 4 months; (iii) the multiple reconstructive osteotomy, which comprised corrective osteotomies, joint realignment, soft tissue balancing, subtalar joint preservation and internal fixation, was performed as treatment; (iv) the pre- and postoperative medical data during the

follow-up period, including X-ray, CT and physical examination, were complete and available; and (v) the follow-up period was at least 2 years. Exclusion criteria included: (i) patients combined with other lower limb injuries; and (ii) patients were diagnosed with comorbidities, which might significantly affect the outcome evaluation (e.g., severe cardiopulmonary insufficiency and hepatic and renal dysfunction, multiple lower limb injury, etc.).

There were 10 patients (eight males, two females) with a mean age of 33.1 ± 7.45 years included in this study. Falling from height was the main cause of the injury, accounting for six of the 10 patients. In addition, two patients were injured from motor vehicle accidents, and falling from stairs and exercise injuries each caused one calcaneal fracture. Among these injuries, the initial fracture types of Sander I, II and III accounted for two, five and three fractures, respectively. Conservative treatment was initially given to all Sanders type I calcaneal fractures and two Sanders type II fractures, with others undergoing surgical treatment with ORIF. Correspondingly, there were two patients with Sanders type I, four patients with Sanders type II, and four with Sanders type III calcaneal malunion. All patients presented with pain in the hind foot or/and the inability to put full weight on the affected limb as their major complaints. Standard radiographs and CT were obtained preoperatively (Fig. 1). All patients were treated with reconstructive surgery at a mean of 5.6 ± 2.41 months since the initial injury. The detailed information and characteristics of the included patients are illustrated in Table 1.

Surgical Technique

Patient Positioning, Surgical Approach and Lateral Wall Exostectomy

The procedure was performed with the patient in a lateral decubitus position on the unaffected side. Combined spinal epidural anesthesia and a thigh tourniquet were utilized as standard procedures.

An extensile lateral "L"-shaped approach was used to expose the calcaneal lateral wall or the surface of the initially fixed internal hardware, which should be removed first for patients who previously underwent ORIF treatment. Lateral wall exostectomy was performed using an oscillating saw

Fig. 1 Preoperative images of malunited calcaneus. (A, B) The lateral and axial views shown by X-ray. A shows a compressed posterior facet with reduced talocalcaneal height and Böhler's angle. (B) shows the varus deformity of the tuberosity. (C–E) The coronal, sagittal and cross-sectional view of malunited calcaneal fracture by CT scan. (C) shows the widened heel, (D) presents a severely compressed posterior facet, yet without obvious signs of osteoarthritis, and a varus deformity could be seen from E

TABLE 1 Characteristics of patients included

No.	Age, (years)	Gender	Time to reconstructive surgery (months)	Initial Calcaneal fracture type (according to Sanders calcaneal fracture classification)	Initial treatment	Calcaneal malunion type (according to Stephens & Sanders calcaneal malunion classification)	Follow-up (years)
1	43	Male	12	Sanders type II	Conservative	Sanders type III	2.1
2	41	Male	6	Sanders type I	Conservative	Sanders type III	2.2
3	23	Male	4	Sanders type II	ORIF	Sanders type II	6
4	39	Male	4	Sanders type III	ORIF	Sanders type II	2
5	30	Male	4	Sanders type II	ORIF	Sanders type I	3.2
6	28	Male	5	Sanders type II	Conservative	Sanders type III	4.1
7	31	Male	6	Sanders type II	ORIF	Sanders type I	2.6
8	25	Male	4	Sanders type III	ORIF	Sanders type III	2.8
9	42	Female	5	Sanders type I	Conservative	Sanders type II	3
10	29	Female	6	Sanders type III	ORIF	Sanders type II	2.4

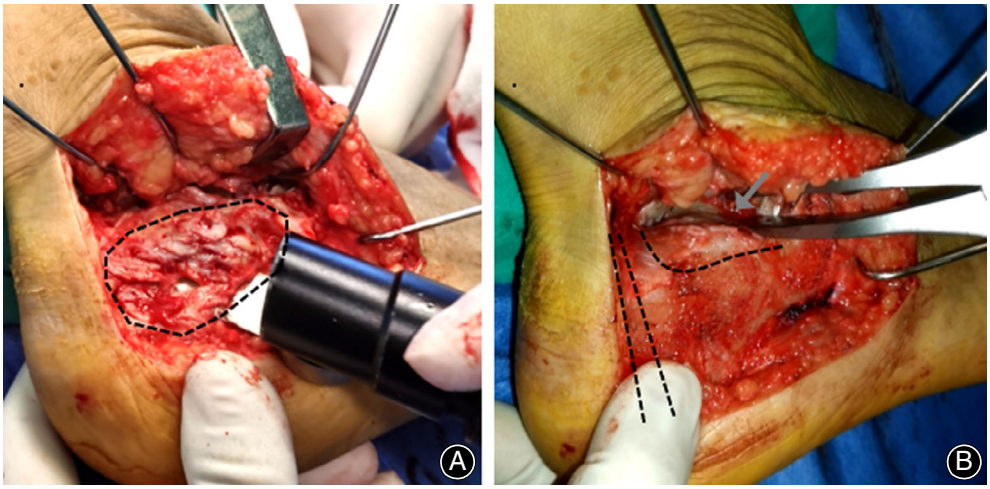

Fig. 2 Intra-operative pictures of lateral wall exostectomy. (A) the region circled by the dotted line was the swollen compact on the lateral wall of calcaneus; (B) a visual assessment of the cartilage of subtalar joint (gray arrow) is conducted after the lateral wall exostectomy. The dotted lines show the following osteotomies

to excise the swollen compact until the level of the subtalar joint was reached, extensively releasing the soft tissue (Fig. 2).

Osteotomies to Restore Subtalar Congruence

A lamina spreader is then placed into the sinus tarsi and distracted to expose the posterior facet of the subtalar joint and assess the condition of cartilage. For the case with an intact articular surface (Sanders type I), the osteotomy was performed 1 cm below the posterior facet so that the fragment with the posterior facet could be mobilized. Then, the posterior facet of the talus was used as a template to adjust the fragment to restore normal subtalar congruence (Fig. 3). The fragment was temporarily fixed with talus using Kirschner wires, and the reduction effect was evaluated radiographically. For the case with a malunited posterior facet (Sanders type II and III), the first osteotomy was performed sagittally along the primary fracture line of the articular surface to recover the smoothness. Then, the osteotomy was carried out 1 cm below the posterior facet, and the fragment with the posterior facet was reduced to the normal contour of the joint and fixed using Kirschner wires. Intraoperative fluoroscopic assessment was performed.

Osteotomies to Reconstruct Calcaneal Morphology

For calcaneal malunions combined with obvious varus deformities (more than 10° varus deformities, Sanders type III), the Dwyer osteotomy was modified. A Schantz pin was placed into the calcaneal tuberosity and used for positioning. Two guide pins were inserted into the calcaneus perpendicular to the tibial axis from lateral to medial. Using an oscillating saw, the first oblique osteotomy was performed starting at a superior point (anterior to the Achilles tendon) to the inferior point (anterior to the posterior calcaneal tuberosity), and the other osteotomy was 1 cm anterior and slanted to the former osteotomy, making the superior part relatively shorter than the inferior part. These two osteotomies were performed from the lateral wall and connected at the medial cortex of the calcaneus, cutting off a "pyramid frustum with triangular bases" shape fragment. The tuberosity was then translated to close the defect with

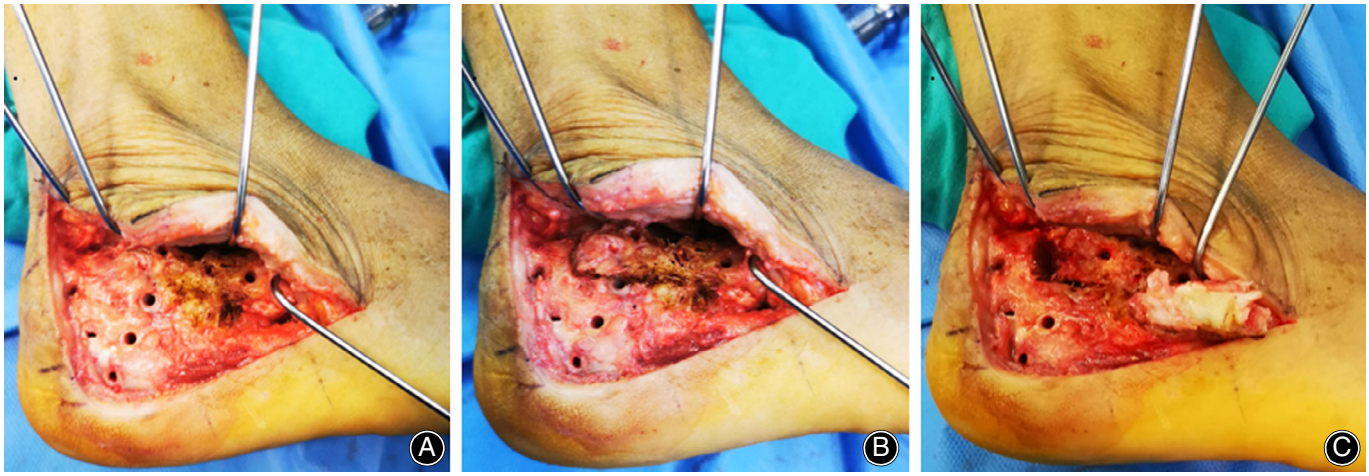

Fig. 3 Intra-operative pictures of articular reconstructive osteotomy. (A) shows an depressed, but almost intact surface of subtalar joint; (B) directive line was sculptured 1 cm beneath the posterior facet using a high frequency electrotome; (C) the fragment with posterior facet is mobilized

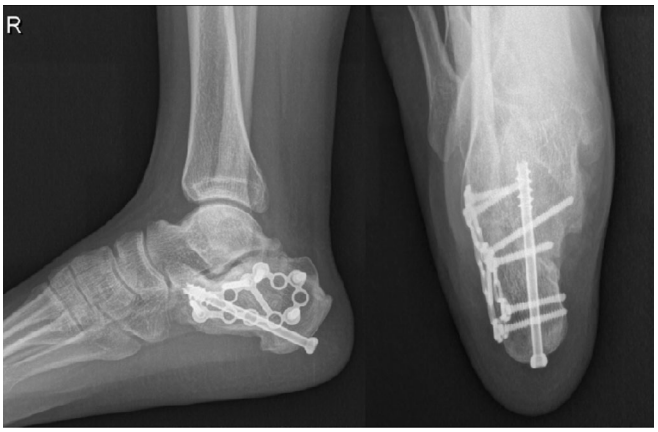

Fig. 4 The lateral and axial views of calcaneus postoperatively showing the calcaneus with normal anatomical parameters such as talocalcaneal height, Böhler's angle, and heal width. And the varus deformity was corrected

a lamina spreader. Once realignment and height of the calcaneal tuberosity was achieved, temporary fixation with Kirschner wires across the osteotomies was performed. The closed reduction could be reduced under fluoroscopy with a calcaneal axial view. Calcaneal plates combined with 6.5 or 7.0cannulatedscrews were used to fix the calcaneus. Radiological examination was performed after the surgery (Fig. 4). The diagram shows the main procedures of the surgery in Fig. 5.

Control and Outcome Evaluation

The efficacy of the multiple reconstructive osteotomy was assessed by comparison between various measurements preoperatively and during the mean time of 3.04 ± 1.21 years (95% CI, 2.17–3.91 years) follow-up period. The functional results were evaluated with the American Orthopedic Foot and Ankle (AOFAS) ankle/hindfoot scale. The measurements of Böhler's angle, calcaneus-talus angle, and talocalcaneal height were performed on pre- and postoperative lateral radiographs, while the aligned relationship of the calcaneal tuberosity was compared on pre- and postoperative axial radiographs. Postoperative clinical examination was focused on the range of motion at the ankle and subtalar joints, which was reflected by active motion of inversion and eversion of the patients.

Study Design

The research was conducted as a retrospective study, in which the preoperative and follow-up clinical data of 10 patients included were collected, reviewed and analyzed.

Statistical Methods

Data are expressed as the mean and 95% CI or the mean and standard deviation (SD) and were compared with paired *t*-tests. A value of $P < 0.05$ was considered statistically significant with the use of a 2-tailed test. All statistical analyses were carried out with IBM SPSS software (version 20.0; IBM Corp, Armonk, NY, USA).

Results

Patients and Follow-up

The10 patients mentioned above were included in the present study and underwent multiple reconstructive osteotomy without subtalar joint fusion. The mean period of follow-up was 3.04 ± 1.21 years. The average time to union was 12.2 ± 1.11 weeks. Partial weight-bearing was started at 8–10 weeks postoperatively. All 10 patients were available for follow-up.

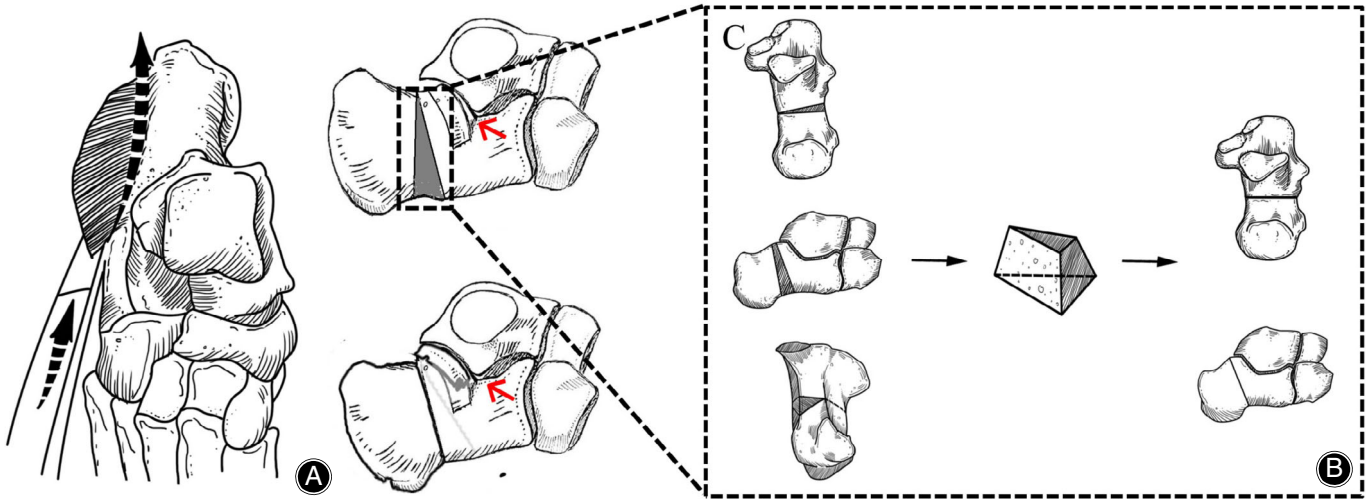

Fig. 5 Diagram showing the main osteotomies performed in the reconstructive surgery. (A) shows the lateral wall exostectomy; (B) shows osteotomies of articular reconstruction and varus recorrect. The two red arrows represent the effect of the articular reconstructive osteotomy; (C) depicts the modified Dwyer osteotomy. A "pyramid frustum with triangular bases" shape fragment is extracted, and the tuberosity is translated to close the defect

Functional and Clinical Outcomes

All patients were subjectively satisfied with the treatment. The mean AOFAS score was significantly improved from 25.4 ± 5.74 preoperatively to 86.3 ± 4.45 ($t = 27.64$, $P < 0.0001$) at the follow-up. The foot loading capability was normalized to the pre-injured state in most of the patients, and no major change was observed through the follow-up gait analysis, which was compared to normal people. A stability test of the ankle showed that no contracture or dislocation of the peroneal tendon occurred during the follow-up period. Because there is no recognized method to measure the motion of the subtalar joint, clinical examination was performed to ask for active motion of inversion and eversion of the hindfoot of the patients to reflect the range of subtalar motion. All the patients who underwent joint-preserving surgery exhibited an almost normal range of subtalar joint movement, with an average degree of 23° in inversion and 10° in eversion. With subjective satisfaction and objectively satisfactory results of clinical and radiography examinations, seven patients initially required removal of the internal fixation after 1 year of reconstructive surgery. The cartilage quality was re-evaluated visually by removing the implant, and an almost intact smooth subtalar joint surface was observed, with no significant cartilage degeneration. Only one patient had mild discomfort after a 1-h brisk walk. Two patients had partial restriction of motion, which did not affect daily activities.

Radiological Outcomes

According to the latest lateral weight-bearing radiographs, the Böhler angle improved to $29.23 \pm 2.64°$ compared with the preoperative 17.01 ± 4.86 degrees ($t = 8.223$, $P < 0.0001$) on average. The mean calcaneus-talus angle increased from $34.46° \pm 6.90°$ preoperatively to $39.7° \pm 6.04°$ ($t = 4.874$, $P = 0.0009$). The mean talocalcaneal height increased from 65.15 ± 22.9 mm preoperatively to 72.68 ± 25.78 mm at the latest follow-up ($t = 5.975$, $P < 0.0001$). The comparison of differences pre- and post-operation in radiographic images is summarized in

TABLE 2 Summary of mean pre- and postoperative radiographic data and *p* values determined by paired *t* tests (N = 10 feet in 10 patients, mean ± SD)

Parameters	Preoperative	Postoperative	*t* value	*p* value
AOFAS score	25.40 ± 5.74	86.30 ± 4.45	27.64	<0.0001
Böhler's angle (°)	17.01 ± 4.86	29.23 ± 2.64	8.223	<0.0001
Talocalcaneal height (mm)	65.15 ± 22.94	72.68 ± 25.79	5.975	<0.0001
Calcaneus-talus angle (°)	34.46 ± 6.90	39.70 ± 6.04	4.847	=0.0009

Table 2. Calcaneal width and varus/valgus deviation were corrected to physiological values.

Complications

One of the 10 patients was suspected of having radiographic arthritis 1 year after surgery, of which the cartilage in surface of subtalar joint showed relative high-density in X-ray images. But the patients could walk normally for a long time without pain. Taking adequate rest and avoiding weight-bearing were suggested and no minor or major postoperative complications occurred.

Discussion

It is the main focus in treating calcaneal malunion that the normal morphology of calcaneous and the congruency of subtalar joint should be reconstructed as far as possible in order to regain the function of hindfoot to the maximum degree. Through osteotomies performed in multiple planes and preservation of subtalar joint, satisfactory results were observed in all the patients who received the novel surgical technique in this study.

Correlation between Deformity and Symptoms in Patients with Calcaneal Malunion

Inappropriately treated displaced calcaneal fracturealways leads to altered calcaneal morphology, including loss of height, heel widening, subfibular impingement, calcaneocuboid joint impingement, varus heel and subtalar joint incongruence, which further causes pain localized to the lateral, anterior, plantar or/and medial foot. Some studies have provided insight into the pain mechanics and reached a consensus on the diagnosis of localization: (i) lateral pain may be the result of peroneal tendon problems, subtalar arthrosis, calcaneocuboid arthrosis, symptomatic hardware, and/or sural nerve problems; (ii) pain localized to the anterior ankle is most commonly caused by anterior impingement of the talar neck on the distal tibia resulting from loss of the calcaneal height; (iii) plantar foot pain or heel pain may result from plantar exostosis or from injury to the heel pad; and (iv) medial pain may be the result of tarsal tunnel syndrome or flexor hallucis longus (FHL) tendon problems.[14–17] Thus, it is the disrupted anatomical relationship of the calcaneus that results in various symptoms following malunited calcaneal fractures, and the goal of surgical management is to restore physical anatomy to maximize the function and lifespan of the joint.

Osteotomies in Treating Calcaneal Malunions

Various corrective osteotomies designed for that target should be a preferable option in treating calcaneal malunions. Braly *et al.*[18] first reported the widely used lateral wall exostectomy as a treatment for malunited calcaneal fractures, and satisfactory results were obtained. A modified lateral wall exostectomy with subtalar joint fusion was then reported by Kassem *et al.*[6] to not only narrow the heel width but also increase the heel height. As for Sanders type III calcaneal malunion, the correction in the axial hindfoot is necessary. Clare *et al.*[19] used lateral wedge closing osteotomy (Dwyer osteotomy) to correct varus deformities and achieved satisfactory results. Subsequently, in order to preserve the calcaneal length, Boffeli and Abben[7] presented a modified Dwyer osteotomy, in which the "wedge" bone graft was rotated and reinserted into the defect of the calcaneus. Inspired by those reconstructed osteotomies, a "pyramid frustum with triangular bases" shape fragment was cut off in our procedure to achieve corrections in multiple planes: the oblique osteotomies in the sagittal plane increases the calcaneal height, while their connection at the medial cortex of the calcaneus corrects the varus deformity. Compared to other osteotomies, this technique allows a multi-reconstruction of calcaneal morphology *via* a simple adjustment of the osteotomy angle. Although a smaller foot may occur, the follow-up data have demonstrated an obvious improvement of the talo-calcaneal height and a relatively neutral resting calcaneal stance position with minimal discomfort.

As for malunion in the subtalar joint, arthrodesis seems to be the common operation, despite the mild or scarcely existent arthritis. However, the subsequent restriction of hindfoot motion might bring about new dilemmas for surgeons.[20–23] Considering this, studies exploring the procedure of subtalar joint-preserving osteotomy for malunited calcaneal fractures were presented. Through recreating primary fracture lines, the "Romash's reconstructive osteotomy" could preserve the subtalar joint and theoretically regain the normal calcaneal morphology to the maximum,[5] while finding the primary fracture line was found to be difficult since the fracture has already achieved union in practice. In addition, reduced calcaneus also raised concerns about whether there is enough soft tissue for covering.[24] Yu *et al.*[25] reported a "tongue"-shaped corrective osteotomy as an alternative method, which raised concerns in their own paper in that the risk of requiring secondary arthrodesis still existed on account of the limitation of an extra-articular osteotomy in dealing with intra-articular malunion. In our technique, the procedure restoring the subtalar joint depends on the integrality of the articular facet. For intact articular surface in Sanders type I calcaneal malunion, the osteotomy beneath the posterior facet, which is meant to mobilize the fragment of subtalar joint, could easily regain the congruence. For a malunited posterior facet with steps in Sanders type II and III calcaneal malunion, the smoothness of the articular surface is should be first recovered through a sagital osteotomy along the primary fracture line, and the osteotomy beneath is subsequently carried out. With intraoperative fluoroscopic assessment, an anatomical reduction of the subtalar joint could be achieved in most cases. The functional and clinical outcomes also indicated that all the patients regained an almost normal range of subtalar movements during the follow-up period.

Indications and Cautions for Multiple Reconstructive Joint-Preserving Osteotomy

Our procedures aimed to address various problems. The first osteotomy of the calcaneal lateral wall could correct the calcaneo-fibular abutment, the following osteotomy beneath the posterior facet could accommodate the relationship of the subtalar joint, and the modified Dwyer osteotomy could restore the height of the calcaneus as well as fix the varus calcaneal deformity. Combined with neurolysis and tenolysis, the pain from tendons and nerves could be relieved. Therefore, based on the different pain locations and correspondingly altered morphology, our method uses single or multiple osteotomy to achieve pain relief as well as structure restoration. Preoperative assessment is important for making decisions regarding joint preservation, and radiological data (radiographs, CT and MRI) are helpful to assess the condition of the subtalar facet. Strict control of the indications of the subtalar-preservation operation is the key to avoiding secondary fusion surgery. Yu *et al.*,[25] in their study, listed some contraindications for performing subtalar-preserving procedures, such as more than 12 months since the fracture and Sanders type IV fracture, since Sanders type IV fractures always feature severely damaged cartilage articular facets. However, patients beyond 12 months were still found to have intact facets, and satisfactory results were achieved with the perceived subtalar joint surgery. Therefore, the time is very suggestive but is not the decisive factor to perform the fusion or preservation procedure. In other words, the key factor affecting the decision is whether there is subtalar arthritis, which is highly related to eccentric loading of the subtalar joint and direct damage to the articular cartilage due to impaction forces at the time of injury. Since most of the patients unloaded their affected feet because of the pain associated with walking, cartilage deterioration was not found to be as rapid as we thought, even for those with calcaneal malunion for more than 12 months. In our experience, the decision could not be made until the subtalar joint surfaces were exposed under direct vision during corrective surgery. The assessment of cartilage includes color, thickness, integrality, and the articular surface is smooth or not. Based on our experiences, the indication of multiple reconstructive joint-preserving osteotomy includes: (i) calcaneal malunion of Sanders type I, II, III fracture; (ii) articular malunion but not developing arthritis; and (iii) reliable patients who comply with the postoperative rehabilitation.[26] Thus, this technique is not recommended for patients with initial Sanders type IV calcaneal fracture or with arthritis of the subtalar joint. To prevent subtalar joint arthritis and algodystrophy after surgery, vitamin C administration could be a good choice because the preferable effect of this nutraceutical in reducing the arthritic symptoms of the knee has been verified in a prospective clinical study.[27] Furthermore, as a natural nutraceutical, vitamin C could exert therapeutic effects with fewer side effects, and oral administration is more acceptable.

The ultimate purpose of any reconstructive orthopedic surgery should be to regain the normal limb function as much as possible. Thus, pre- and postoperative functional evaluation plays an important role in the comparison of various surgical methods. For the lower limb, foot loading testing and gait analysis are recommended to be utilized together to evaluate the therapeutic effect.[28] Moreover, although no minor or major postoperative complications occurred in our study, the peroneal tendon could always be a focus. Even the laterally located tendon, which commonly suffers from the first injury of the calcaneus, is generally carefully released and protected during surgery, the relapses of traumatic peroneal tendon subluxation still cannot be ignored. A new surgical approach dealing with the aforementioned dislocation was recently reported. By removing scar tissue, reattaching the retinaculum using suture anchors and strengthening it with an acellular dermal matrix allograft patch, an excellent result was observed, which also made the novel surgical technique an accessory choice for treating calcaneal malunions.[29]

Strengths and Limitations

This research proved that multiple constructive osteotomy, which comprises lateral wall exostectomy, modified Dwyer osteotomy and osteotomies accommodating the relationship of the subtalar joint, is an efficient method of management for different types of calcaneal malunion. With careful assessment of cartilage preoperatively, the results showed that no patient underwent secondary fusion during a mean follow-up period of 3.04 years. However, there is also a disadvantage that needs to be pointed out. The modified Dwyer osteotomy in our procedure could cause a smaller calcaneus and smaller feet, although there is no evidence showing that the smaller feet have any relevance to motor function. In addition, the limitations of this research include the relatively small number of patients. Biomechanical experiments are being processed to assure superiority.

Conclusions

Multiple reconstructive calcaneal osteotomy with subtalar joint preservation could be an effective surgical technique to restore the function of the subtalar joint, reconstruct the morphology of the calcaneus and alleviate pain for selected patients with different types of calcaneal malunions. Comprehensive assessment of the subtalar joint cartilage plays an essential role in the success of the surgery. However, considering the limited number of patients in this study, our results still need to be validated in a larger number of cases. According to the present outcomes, multiple calcaneal osteotomies with subtalar joint preservation could be recommended for use in managing calcaneal malunions with mild osteoarthritis.

Author contributions

B. Yu and D. Xiang designed the research; D. Xiang and B. Wang performed surgeries; B. Wang, X. Guan, Y. Hu, G. Jiang, Q. Lin and J. Ye collected and analyzed data; B. Wang and X. Guan wrote the paper; B. Yu and D. Xiang supervised the research and revised the manuscript.

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