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Original Article

Comparison of the biomechanical function and clinical effects of plate and multi-pin fixation in the treatment of Sanders II calcaneal fractures

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Abstract: The aim of this study was to compare the biomechanical function and clinical effects of plate and multi-pin fixation in the treatment of Sanders II calcaneal fractures. A three-dimensional finite element model of the Sanders II calcaneal fracture was established by subtracting several unit structures from the normal model from a healthy volunteer. The fractured calcaneal were reduced and fixed with a steel plate or multi-pin. Loading of the fractured calcaneus via the tendo calcaneal was simulated and the resulting von Mises stresses and equivalent strain were observed at 0° (neutral position) for plate group, and at 0° (neutral position) and 30° (plantar flexed position) for multi-pin group, respectively. Finally, a retrospective clinical study was conducted, in which 59 patients received either the steel plate or the multi-pin fixation was surveyed for satisfaction as well as soft tissue complications. The von Mises stress values at 0° for plate group, and at 0° and 30° (plantar flexed position) for multi-pin group were 144.69 MPa, 167.27 MPa, and 176.92 MPa, respectively. The equivalent strain of fracture line at 0° for plate group, and at 0° and 30° (plantar flexed position) for multi-pin group were 0.44 mm/mm, 0.22 mm/mm, 0.21 mm/mm respectively. The multi-pin fixation had a slightly higher excellent and good rate compared to the plate fixation (83.4% vs 78.3%) ($P > 0.05$). Calcaneal plate fixation had a higher overall rate of the soft tissue complications than that of the multi-pin fixation ($P < 0.05$). Our findings suggested multi-pin fixation may be a better method for Sanders II calcaneal fractures as such fixation will provide a higher fracture biomechanical stability than plate internal fixation and possibly reduced soft-tissue injury.

Keywords: Sanders II calcaneal fracture, multi-pin fixation, plate fixation, finite element

Introduction

Calcaneal fracture is the most common fracture which accounts for about 2% of all fractures and 60%-65% of the tarsal fractures [1, 2]. These fractures can be extra-articular or intra-articular fractures, with intra-articular fractures constituting approximately 60% to 75% of all calcaneus fractures [3, 4]. The calcaneal fracture, especially the intra-articular fracture, severely damages the talocalcaneal joint or the calcaneocuboidal joint. Hence, it can be usually associated with secondary traumatic arthritis and severe motor dysfunctions such as weight-bearing pain, adhesion and stiffness of the injured foot [5, 6]. Surgery is currently the most widely accepted treatment approach for intra-articular calcaneal fracture as it provides better patient-related outcome [6-8]. However, due to complex anatomical structures around calcaneus, various fracture types and poor ability against ischemic necrosis and wound infection of surrounding soft tissue, patients with intra-articular calcaneal fractures are difficult to treat and have more chance to get postoperative complications [7, 9]. Thus, the selection of correct fixation for fracture treatment remains challenging and often controversial [10, 11].

Calcaneal plate fixation is the widely accepted surgical technique for intra-articular calcaneal

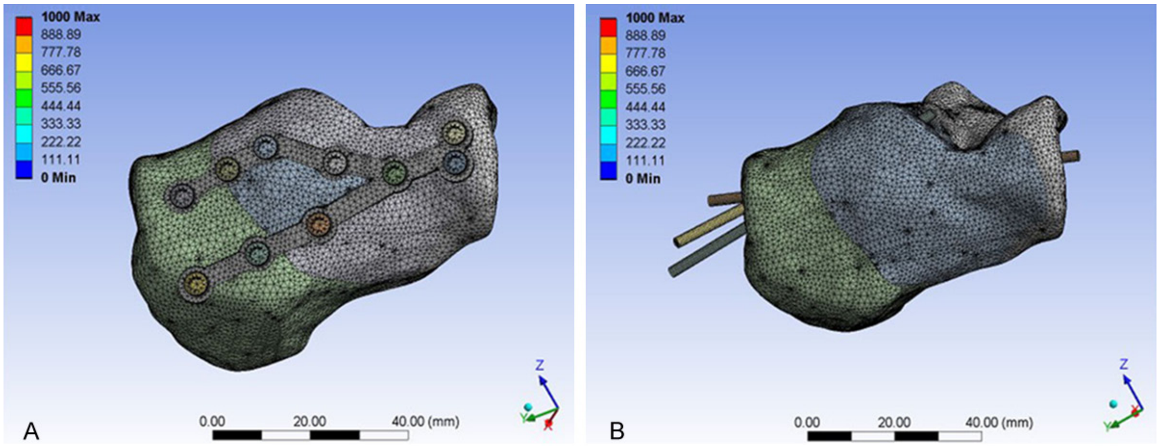

Figure 1. Three-dimensional finite element model of plate fixation (A) and multi-pin fixation for calcaneal fracture (B).

Table 1. The mechanical properties of the different materials

Materials	Young's modulus (MPa)	Poisson's ratios
Cortical bone	7300	0.3
Cancellous bone	100	0.3
Fracture line	5	0.4
Steel plate and screws	2×10^5	0.28
K-wire (2 mm)	2×10^5	0.28

fracture because it can effectively increase the stability of the fracture during the healing period and reduce re-displacement [12, 13]. However, it is also associated with complications such as wound edge necrosis, dehiscence, hematoma, deep infection, or neurovascular injuries due to large plate size and surgical incision [7, 13]. To prevent or lower wound complications and associated problems, alternative techniques using minimally invasive multi-pin fixation has been recommended by several clinicians [14-16], with an advantage of a decreased incidence of wound complications and reliable improvement in patient recovery. However, multi-pin fixation is often questioned regarding its fixation stability. Therefore, it is still controversial whether multi-pin fixation technique is a more appropriate modality for the intra-articular calcaneal fracture. The aim of our study was to compare the biomechanical and clinical outcomes of steel plate and multi-pin fixation for the treatment of calcaneal fracture. Our study provides a basis for the selection of optional fixation method for the treatment of Sanders II calcaneal fracture.

Materials and methods

Subject for biomechanics simulation

This study was approved by the ethical committee of Xiangya Hospital, Central South University (No. 201605584). A 28-year-old healthy male volunteer gave his written informed to participate in our study. He was 176 cm tall and weighed 64 kg. The subject did not have any previous medical history and surgery, X-ray examination showed no exception, congenital malformation and osteoporosis.

Model reconstruction

Spiral computed tomography (CT) scanning was performed on the right foot by using a 16-slice CT scanner (Light Speed, General Electric Company, CT, United States). The scanning parameters were as follows: scanning slice thickness (0.299 mm), scanning voltage (130 kV), scanning current (60 mA), and scanning resolution (0.55 mm). 339 slices were obtained. The CT images were imported into image processing software MIMICS 15.0 (Materialise, Leuven, Belgium), in which the bone contour was obtained. Then, a solid model of the calcaneus was constructed in MIMICS 15.0. The model underwent further segment and assembly. These data were then imported to the Unigraphics NX 7.5 (Siemens PLM, Germany) to produce a three-dimensional finite element model of the Sanders II calcaneal fracture according to the definition of the Sanders classification. The model of the calcaneal fractures fixed by AISI 316L surgical stainless steel plate and

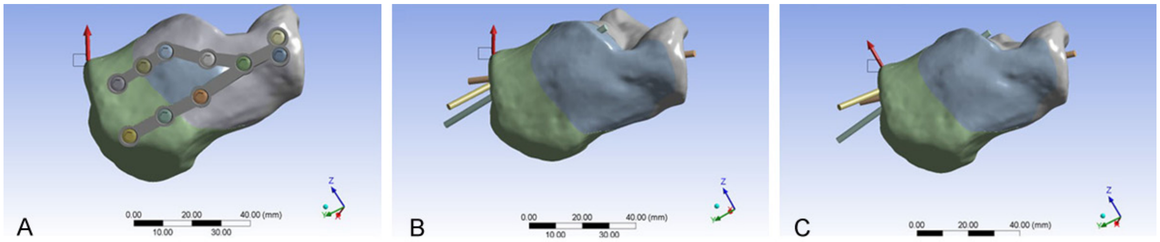

Figure 2. A vertical force of 160 N was applied on the fractured calcaneus via the Achilles tendon at 0° (neutral position) for plate group (A), and at 0° (neutral position) and 30° (plantar flexed position) for multi-pin group (B&C), respectively.

multiple 2-mm Kirschner wires (K-wires) were loaded into and assembled in the Unigraphics NX 7.5 software and thus two kinds of internal fixation model were established (**Figure 1**) according to the design of the experiment. A fine mesh (464,346 nodes and 258,148 quadratic tetrahedral elements for multi-pin fixation model and 570,962 nodes and 347,645 quadratic tetrahedral elements for plate fixation model) was constructed to simulate the surgery. The cortical and cancellous bones were idealized as homogenous, isotropic, and linearly elastic. The elastic constants of the different materials were set as shown in **Table 1**. These parameters were measured and referred from previous research studies [17-19].

Boundary and loading conditions

For a 64 kg person, the force on a single foot was approximately 320 N during the static non-weight-bearing condition. According to the previous reports, the force on the Achilles tendon was approximately 50% of that of the foot during the static non-weight-bearing condition [20, 21]. Therefore, the corresponding force of the Achilles tendon during the bipedal standing was approximately 160 N. The force at the end of the tendo calcaneal should be no more than the maximum value of 160 N during the non-weight-bearing condition. A vertical force of 160 N was applied on the fractured calcaneus via the Achilles tendon was simulated (**Figure 2**) and the resulting von Mises stress and equivalent strains were observed at 0° (neutral position) for plate group, and at 0° (neutral position) and 30° (plantar flexed position) for multi-pin group, respectively. The reason that no 30 degree test for the plate group was because patients was directly placed in the 0° neutral position after plate fixation in clinic wherein patients those undergoing multiple pin fixation should be fixed at 30° plantar flexed position and then at 0° (neutral position). The reason that we studied the 30° plantar flexed position for pin fixation was that surgeons usually put patients in plantar flexed position and then neutral position due to the concern for pin fixation stability in clinic. The peak von Mises stress was calculated for each part of this model. The von Mises stress is based on the von Mises yield criterion, which assumes that the material yielding begins when the second deviatoric stress invariant reaches a critical value. Its peak value is often used in biomechanics to evaluate and predict tissue injuries [22, 23]. In this study, the von Mises stress was used to describe the stability of plate and multi-pin fixation materials under loading conditions. The equivalent strains were used to describe the relative displacement of fracture line. The Achilles tendon was attached to the 1/3 posteroinferior aspect of the calcaneal tuberosity with a medial inclination. Posterior subtalar articular surfaces and calcaneocuboid articular surfaces of the calcaneus were restrained.

Subjects for clinical survey

We retrospectively collected clinical data of 59 patients with Sanders II calcaneal fractures who were treated by internal fixation with multi K-wires or steel plate at our hospital from January 2007 to December 2010. The diagnosis of Sanders II calcaneal fractures was made based on the coronal and axial calcaneal CT. The patients consisted of 37 males and 22 females. The mean age was 40.5 years old (range, 18-55 years). 19 cases have fractures at left calcaneus while the remaining 40 fractures at the right side. The intervals between injury and diagnosis were 1-72 hours. Most of the injuries were caused by falling from high. 4

Figure 3. Photograph showing the trend of surgical incision of plate fixation (A) and multi-pin fixation (B).

cases had concomitant vertebral compression fractures, 3 cases had concomitant cuboid fracture and calcaneocuboid joint dislocation. 3 cases had concomitant scaphoid fracture. All subjects underwent calcaneal lateral and axial X-ray scanning and the axial and coronal CT scanning of calcaneus. The entire patients is divided into two groups according to the surgical modalities including multi-pin internal fixation group (n=23) and the steel plate fixation group (n=36).

The inclusion criteria were as follows: 1) Sanders II calcaneal fracture; 2) Age range: 18-55 years old.

The exclusion criteria were as follows: 1) patients with open fracture of calcaneal; 2) soft tissue with poor coverage defect; 3) patients who are unable or rarely walk prior to the surgery; 4) patients with psychological diseases; 5) patients with limb sensory recession or loss induced by diabetes or other nervous system disease; 6) patients with severe systemic disease, such as heart failure, liver and kidney failure; 7) patients with severe osteoporosis; 8) tongue-type calcaneal fractures and Sanders I, III, IV fracture; 9) patients with congenital developmental abnormality; 10) patients with vascular disease and other systematic inflammatory disease; and 11) severe obese patients whose Body mass index ≥ 25 kg/m^2.

For clinical analysis, all patients had comprehensive physical and imaging examination and received symptomatic treatment for general issue. Preoperatively, all patients underwent 10 to 14 days of anti-edema therapy. After anti-edema therapy, the swelling subsided and the skin on the lateral part of heel showed wrinkle signs indicative of extinction of edema. All the operations are performed by a group of 3 attending surgeons with more than 10 years surgical experience.

Open reduction and plate fixation

The patients were placed in the lateral decubitus or supine position. The tourniquet was utilized routinely. An incision was made longitudinally from 3-5 cm above the tip of the lateral malleolus to the conjunction region of the dorsal skin of foot and thenar skin. Then the incision was turned 90° at heel and extended forward to 1-2 cm proximal side of the base of the fifth metatarsal (**Figure 3A**). Part of the inferior extensor retinaculum was incised and the branches of the sural nerve were protected. Subperiosteal dissection was performed along the lateral wall. The peroneal tendons and flap were lifted above the articular surface of calcaneus and talus. Thereafter, the prominent lateral wall was pried with a periosteum detacher to fully expose the subtalar joint. The inner and outer lateral walls were pushed to correct the width of calcaneus and then the posterior articular surface of calcaneus was aligned with articular surface of talus. Bone grafting was performed to repair cancellous bone defects using autologous bones. The reduction was verified with X-ray. After reduction was achieved, 316L stainless plate was placed on the lateral side of the lateral wall. Screws were fixed into the sustentacular process, calcaneal tuberosity, and front heel portion, respectively. Plaster immobilization at neural position were initiated immediately after surgery. Wound was then sutured and drainage tubes were placed. Drainage tubes were removed 48 hours after surgery and patients started ankle exercise 6 hours after surgery. Stitches were removed after 2-3 weeks of surgery and weight-bearing activities were started 8-12 weeks after surgery.

Open reduction and multi-pin fixation

The patients were placed in the lateral decubitus or supine position. The tourniquet was utilized routinely. An incision was made from 3 cm above the tip of the lateral malleolus to the 1.5-2 cm below the lateral malleolus and extended to the cuboid bone (**Figure 3B**). Peroneal nerve was carefully protected during sur-

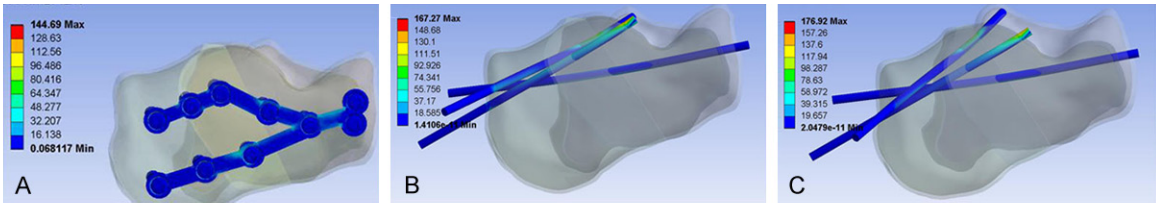

Figure 4. The von Mises stress at 0° (neutral position) for plate group (A), and at 0° (neutral position) (B) and 30° (plantar flexed position) (C) for multi-pin group.

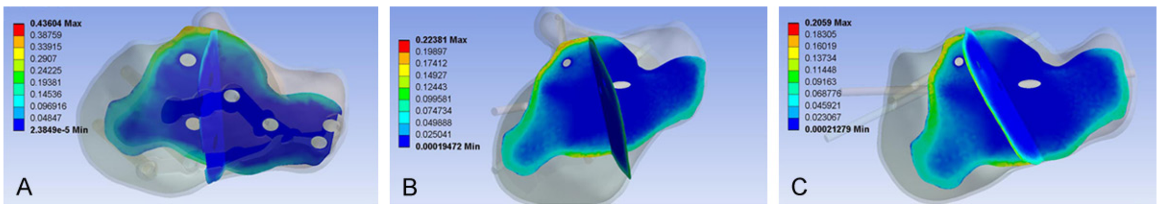

Figure 5. The equivalent strain of fracture line at 0° (neutral position) for plate group (A), and at 0° (neutral position) (B) and 30° (plantar flexed position) (C) for multi-pin group.

Table 2. The general information of the subjects (means ± SD, n=5)

	Plate fixation group (n=23)	Multi-pin fixation group (n=36)	*P* values
Male/Female	13/10	24/12	0.34
Age (yr)	39.08±11.90	42.00±10.67	0.15
Height (cm)	168.54±10.05	173.32±12.57	0.22
Body mass (kg)	65 (49~82)	69 (51~88)	0.09
Injury side (*n*, left/right)	8/15	13/23	0.13
Injury mechanism			
Tumbles wound	5	7	0.48
Falling from high	13	25	0. 43
Sports related	5	4	0.79

gery. Calcaneofibular ligament was incised and the lateral wall of the calcaneus was opened to expose the collapsed subtalar joint. Articular aspects of the posterior subtalar joint were lifted by osteotome. If there existed calcaneocuboid joint dislocation and fracture, calcaneal gross appearance was observed after reduction. Lateral compression was performed to correct the width of calcaneus and the deformity. After obtaining good reduction, K-wires (2.0-mm) were placed into the talus bone, cuboid bone, and sustentacular process, respectively. The reduction was verified with X-ray. In order to restore the height of the calcaneus, bone grafting was performed using autologous bones. Wound was closed and drainage tubes were placed. K-wires were bended and leaved out of the skin. Drainage tubes were removed 48 hours after surgery and patients started ankle exercise 6 hours after surgery. Stitches were removed after 2-3 weeks of surgery. Plaster immobilization were initiated at 30° (plantar flexed position) for 3 weeks followed by 0° (neutral position) for 3 weeks and removed after fracture line disappeared on X-rays. Weight-bearing exercises of ankles were not conducted. Multi-pin internal fixation was removed according to the process of the healing. The patients started walking exercises with or without crutches 8-10 weeks after surgery.

Follow up and clinical evaluation

The mean follow up time was 15±3.5 months with a range from 12 to 26 months. During the follow up, radiographs were used to evaluate the reduction and the union. The fracture was defined as united by the disappearance or indistinct fracture lines on x-ray. Soft tissue complication such as skin edge necrosis, incision infection, pin tract infection, lateral sural cutaneous nerve injury, heel pressure ulcers and peroneal tendon tenosynovitis were recorded.

The functional status was assessed using the Maryland Foot Score 12 months postoperatively [24]. The scale can be categorized as excellent (90-100), good (75-89), fair (50-74), and poor (5-50). A higher score on the Maryland Foot Score equates to a higher level of patients condition.

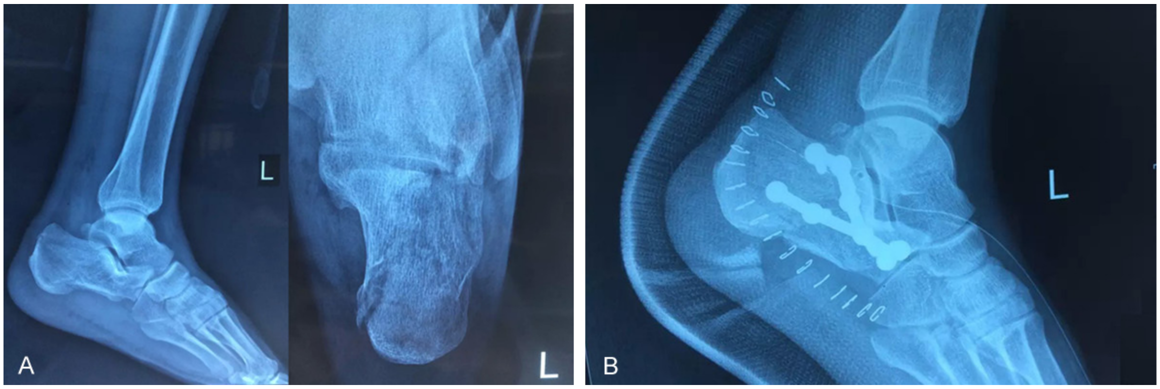

Figure 6. A 36 year old male patient with calcaneal fracture of left foot was treated by open reduction and plate fixation. Preoperative radiograph (A) and postoperative radiograph (B).

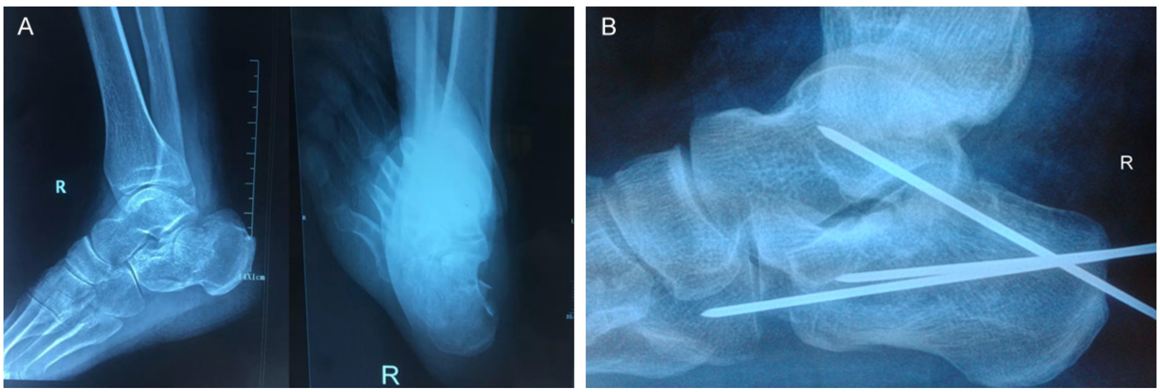

Figure 7. A 28 year old male patient with calcaneal fracture of right foot was treated by minimally invasive open reduction open reduction and multi-pin fixation. Preoperative radiograph (A) and postoperative radiograph (B).

Statistical analysis

Data analysis was performed by using SPSS 13.0 software (SPSS Inc., Chicago, IL, USA). Quantitative data were expressed as mean ± SD and compared *by using* independent-samples T test. Qualitative data are analyzed using χ^2 test or rank-sum test as appropriate. Differences were considered statistically significant when $P < 0.05$.

Results

As shown in **Figure 4**, the von Mises stress at 0° (neutral position) for plate group, and at 0° (neutral position) and 30° (plantar flexed position) for multi-pin group are 144.69 MPa, 167.27 MPa, and 176.92 MPa, respectively.

As shown in **Figure 5**, after maximum loading of 160 N, the equivalent strain of fracture line at 0° (neutral position) for plate group, and at 0° (neutral position) and 30° (plantar flexed position) for multi-pin group are 0.44 mm/mm, 0.22 mm/mm, 0.21 mm/mm respectively, which all lower than the operation indication of the calcaneal intra-articular fracture (≥ 1 mm) [25]. These findings suggest that multi-pin internal fixation has a higher biomechanical stability than plate internal fixation.

Clinical survey

The clinical characteristics of all the patients are shown in **Table 2**. There was no statistically significant difference regarding the gender, age, height, body mass index, injury side, and cause of the injury between the plate fixation group and the multi-pin fixation group.

The mean duration of follow-up is 15 months with a range from 12 to 26 months. All fractures were healed within 8-12 weeks after surgery. **Figures 6** and **7** shows preoperative and

Table 3. Maryland foot score in two groups after operation (means ± SD)

Maryland score	Plate fixation group (n=23)	Multi-pin fixation group (n=36)
12 months postoperatively	82.35±13.13 (65.09-93.74)	84.31±13.45 (69.61-94.18)

Table 4. Comparison of the functional outcomes of plate fixation and multi-pin fixation

Groups	*n*	Excellent	Good	Fair	Poor	Excellent and good rate	*P*
Plate fixation group	23	8 (34.8%)	10 (43.5%)	4 (17.4%)	1 (4.3%)	78.3%	0.569
Multi-pin fixation group	36	15 (41.7%)	15 (41.7)	4 (11.1%)	2 (5.5%)	83.4%	

Table 5. Postoperative complications of the plate fixation and multi-pin groups

Complications	Plate fixation group (n=23)	Multi-pin fixation group (n=36)
Incision infection	2	2
Skin edge necrosis	3	0
Peroneal tenosynovitis	1	0
Lateral sural cutaneous nerve injury	2	1
Pressure ulcers	0	1
Pin tract infection	0	2
Total (P < 0.05)	8 (34.8%)	6 (16.7%)

postoperative radiographs and photographs from two representative cases. According to Maryland foot score, 8 fractures resulted excellent (90-100 points), 10 good (75-89 points), and 4 fair (50-74 points), with excellent/good rate of 78.3% (18/23) in plate group, while 15 fractures resulted excellent, 15 good, and 4 fair, with excellent/good rate of 83.4% (30/36) in multi-pin group, which was not statistically significant different between two groups (P > 0.05) (**Tables 3** and **4**).

Of the 36 cases in the multi-pin fixation group, there were 6 cases of soft tissue complications including 2 cases of incision infection which healed well after the drug treatment, 2 cases of pin tract infection, 1 case of lateral sural cutaneous nerve injury and 1 case of heel pressure ulcers. In the steel plate fixation group (n=23 cases), 8 cases had soft tissue complications. Of the 8 cases with postoperative soft tissue complications, there were 3 cases of skin edge necrosis and skin defect due to plate exposure (patient treated by debridement, plate removal and flaps transplantation after 60 days of fixation). There were also 2 cases of incision infection which healed after the drug treatment, 1 case of peroneal tenosynovitis which relieved after local blocking with 2.5-5 ml of triamcinolone acetonaide acetate injection, and 2 cases of lateral sural cutaneous nerve injury which healed by administrated oral drugs. The overall incidence rate of the soft tissue complication in multi-pin fixation group is lower to that of the steel plate fixation group (P < 0.05) (**Table 5**).

Discussion

As the in-depth knowledge of the mechanism and the classification of the calcaneal fracture, the clinicians have extensive experience in the fracture treatment and prospective curative effect. The operative treatment is an important method in dealing with calcaneal fracture, particularly the intra-articular fracture which is the consensus of majority of the orthopaedic surgeon. However, the complex anatomical structure, various fractures types, the weak resisting ability of the skin and soft tissue surrounding the calcaneal to resist ischemic necrosis and infection of the calcaneal increase the difficulty of the surgery and the long-term curative effect is difficult to predict, which is a huge challenge for traumatic orthopedic surgeons [5, 26]. The calcaneal fracture has yet to reach a unified viewpoint in the respects of classification, therapy, surgical technique and postoperative management.

With the development of the radiological technology and surgical technique, the role of recovering the anatomic relationship of the local arthrosis and solid internal fixation takes up a more important position in recent years. At present, open reduction and internal fixation is the widely accepted surgical approach for the displaced calcaneal fracture. The fixed material includes the steel needle, steel plate, screw and the first two in common use. The fixation of the calcaneal fracture should be accord with the biomechanical characteristics of the hind foot. It is difficult to establish the tough fixed structure after the internal fixation due to the major component is cancellous in the calcaneal and the bone trabecula is relatively sparse in the front and the central region, and the peripheral cortical bone is relatively thin [27]. Therefore, when considering the selection of the types of internal fixation, the scruples such as that the multi-pin is unable to implement the early weight-bearing training can be set aside.

The finite element method is frequently employed to simulating the authentic human condition and provides quantitative parameters for clinical diagnosis. The study aimed to compare the characteristics of the two internal fixation types through the biomechanics analysis. The stress distribution of the internal fixation is the significant judgment standard of the curative effect. The ideal internal fixator can distribute the stress in average instead of concentrating in one point. The steel plate group and multi-pin group both average the stress on the fixator and the maximum principle stress both less than the yield strength (225 MPa), which indicate the steel plate and the multi-pin are both the suitable fixators. The relative displacement of the calcaneal fracture line can indicate the stability of the internal fixation. The relative displacement of the steel plate group and the multi-pin internal fixation group both less than the criteria of the operation indication of the intra articular fracture of calcaneal (displacement $\geq$ 1 mm). This result indicates the stationarity of the fixation methods for the fracture. However, the solid steel plate may influence the surface reconstruction of calcaneal and induce the bone absorption and osteoporosis. As to the stress shielding of the steel plate, the assessment still need the further verification by biomechanics experiment.

Incision complication after the calcaneal fracture is the principal calcaneal surgical complication in the present which can impact the functional recovery of the sick calcaneal. The steel plate internal fixation can fix the calcaneal fracture easily and steadily which is the most admired therapy method. But for the Sanders II and a portion of Sanders III fracture, the contour of the steel plate is relative huge with a longer incision, large trauma, excessive bleeding and relative abundant peeled soft tissue. Sometimes the placement of the steel plate is untoward and it is easy to induce complications like skin injury, the tendon and nerve stimulating. Moreover, it has been reported that steel plate internal fixation often accompanied with the local infected steel plate exposure.

Previous report suggests that the outer layer of soft tissue is most prone to infection which may due to the blood supply only can via the lateral calcaneal artery [28]. Due to the relative thin soft tissue covering the calcaneal, it is more prone to postoperative infection and the edge of the lateral L-shaped incision often generate the necrosis which may relate to the blood of this region supplied by the peroneal artery [29]. Compared to the lateral L-shaped incision of the steel plate, the small arc-shaped incision of the multi-pin internal fixation has lesser destruction to the lateral thin soft tissue. In terms of the soft tissue around the calcaneal, small incision and less peeling corresponds to the low risk which is the feature of the multi-pin style. The X-ray radiographs after the fixation and the corresponding incision shapes are shown in **Figure 3**. This is beneficial to the knitting and stronger ability to resist the contraction force of the tendo calcaneal, and it also can avoid the calcaneal deformation after the operation. The nail end is left outside and the implant can be taken out expediently which is in favor of reducing the psychological burden of the patients. This investigation indicates that the steel plate and the multi-pin group have the similar fixation effect while the complication incidence of the soft tissue in the steel plate group is higher than that in the multi-pin group.

The suitable treatment before and after the calcaneal fracture surgery also impact the complication condition [30, 31]. Firstly, pinpoint the correct fracture type based on the correlative index on the X-ray radiograph, CT-scan and the 3-dimensional reconstructed images. Then evaluate the local and whole situation of the soft tissue and formulate the suitable therapeutic regimen. Especially for the evident swelling foot, should perform the detumescence dehydration processing and lift the swelling foot for improving the soft tissue condition. But for the patients with relatively poor condition, improving the underlying disease and cardiopulmonary function first and the smoke-free environment are significant. The observation of the skin incision margin is crucial on the first postoperative day because if the blood transportation is bad near the suture, the suture should be dismantled immediately. Meanwhile, lift the swelling foot and enhance the toes movement. Therefore, the detail treatment is the important safe guards in preventing the operative complications.

Conclusions

The multi-pin internal fixation is a suitable option for the patients with Sanders II calcaneal fractures due to such fixation can provide a higher fracture stability and possibly reduced soft-tissue injury than plate internal fixation. Further studies are warranted.

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Disclosure of conflict of interest

None.

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