Minimal invasive mini-rail external fixation for surgical treatment of calcaneal fractures

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The purpose of this study is to evaluate and promote the application of percutaneous minimal invasive uniplanar mini-rail external fixation for definitive fixation for displaced calcaneal fractures. This technique has been promoted to avoid soft tissue complications commonly seen with calcaneal open reduction internal fixation, and allows to apply skeletal traction and fracture reduction through ligamentotaxis with percutaneous fixation of the posterior facet fragments without the need to delay surgery secondary to edema. In this retrospective study, application of four 3.0mm stainless steel partially threaded half pins were applied across an intra-articular calcaneal fracture, 2 proximal and two distal, allowing for longitudinal traction and stabilization following reduction. Clinical outcomes were determined with a minimal 12-month follow up and a American Orthopedic Foot and Ankle Score (AOFAS) hindfoot score questionnaire. We evaluated and surgically managed 21 patients who presented to the emergency department with closed calcaneal fractures in a 6-year period, beginning from the year 2014 to 2020 with mini-rail fixation. Of the 21 patients, 12 (57%) participated in this study and were also evaluated by physical examination. Regarding patient satisfaction with minimal invasive percutaneous mini-rail fixation, patients reported an average AOFAS score of 82.1, 91% (11/12 patients) and were able to return to work, and only 1 patient required an additional surgery. The clinical results are comparable with traditional open reduction internal fixation with no soft tissue disruption, avoidance of internal fixation plates/screws, and allows for early mobilization.

Keywords: calcaneal, fracture, minirail, external fixation, calcaneus, MIS, minimally invasive, monorail

To this day, there remains no formal consensus regarding surgical management of displaced intra-articular calcaneal fractures with minimal potential complications. Displaced intra-articular fractures of the calcaneus are usually the result of high-energy trauma encountered with falls from a significant height or high-speed motor vehicle accidents. Surgical intervention for displaced calcaneal fractures remains controversial, however for optimal treatment it is universally accepted restoration of calcaneal height, width, frontal plane varus correction with complete reduction of posterior articular facet of subtalar joint reduces the complexity of subsequent post-traumatic arthritis [1-5]. Soft tissue compromise with high incidence of skin dehiscence, healing issues, infection are well known after a full-thickness lateral extensile exposure for calcaneal open reduction internal fixation. Conn et al., in 1935 stated calcaneal fractures are “serious and disabling injuries in which the end results are incredibly bad” [6]. Surgical treatment of displaced intra-articular calcaneal fractures pose a challenge to many surgeons due to complicated hindfoot anatomy that is subjected to compressive forces along articular facets with the talus within the subtalar joint as well as Chopart’s joint which alters associated biomechanics for patient. Calcaneal fractures require unique and additional surgical considerations, as it has been well documented of incidence of soft tissue wound dehiscence, symptomatic hindfoot stiffness (distinctly when residual varus is present), post-traumatic osteoarthritis of subtalar and calcaneocuboid joints, and potential osteomyelitis secondary to extensive soft tissue compromise with these injuries [7-10].
The use of external fixation is acceptable, and warrants for definitive management for open or closed calcaneal fractures that are not amenable to open reduction internal fixation.

Patients/Materials and Methods

Subjects

After institutional review board (IRB) approval was obtained, a registry of patients with operatively repaired intra-articular calcaneal fractures from 2015 to 2020 were identified. All patients presented to two local Florida hospitals for evaluation and management for acute calcaneal fractures with one primary surgeon. Inclusion criteria included: 1) Age > 18 years old, 2) No open soft tissue envelope compromise 3) Underwent percutaneous mini-rail mono-planar external fixation reduction at one of the study locations, 4) No lateral L-style extensile extensile or sinus tarsi incision needed, 5) Minimal 1 year follow up, 6) Minimum 3-view plain film radiograph obtained on initial emergency department consultation. Exclusion criteria were: 1) Open fracture or soft tissue envelope disruption, 2) Chronic injuries, 3) Less than 1 year follow-up. In this retrospective study, we evaluated 21 patients who presented to the emergency department with acute, closed calcaneal fractures in a 6 year period, only 1 patient presenting with bilateral fractures. Based upon inclusion/exclusion criteria nine were excluded, leaving a total of 12 calcaneal fractures participating in this study. All patients received fundamental plain film 3-view foot x-ray series, and received advanced imaging of computerized tomography (CT) unless there was no comminution suspicion of intra-articular fracture. All fractures were analyzed, and classified according to the Rowe classification system with the standard plain film 3-view foot series. If CT scans were obtained, Sanders classification was utilized to analyze and classify the pathology with an axial-view of the widest aspect of the calcaneal posterior facet. Retrospective chart review was then performed for collection of patient information including age, past medical history, sex, characteristic of fracture pattern.

Surgical Technique

A total of four 3.0mm stainless steel partially-threaded half-pins were applied across an intra-articular calcaneal fracture for our mini-rail external fixation construct, 2 proximal and 2 distal to the fracture site. First, a partially threaded 3.0mm half-pin was inserted perpendicular to the calcaneus, proximally to the fracture, under fluoroscopy imaging. The mini-rail external fixation device was placed over the first pin, then aligned to the fixator so distal pin clamp position where the provisional second half-pin would be placed over the calcaneus where optimal longitudinal traction would be most appropriate. The internal pin clamp was adjusted to the appropriate length of the external fixator to allow the provisional distal half-pin in the desired location. The second partially threaded half-pin was then inserted by power through the fixator which is used as a guide perpendicular to the calcaneus. Fluoroscopy was utilized to check penetration through the far cortices allowing for two threads past, however not passing greater than 2mm past the bone cortex. Once confirmed with fluoroscopy, appropriate pin length as well as successfully crossing the fracture site, insertion of the third and fourth pin through the external fixator was performed in a similar fashion as the first two pins.
Distance between the skin and external fixator allowed adequate clearance to permit soft tissue swelling. The four half-pins were tightened appropriately to the pin-clamp within the mini-rail. At this time under live fluoroscopy, longitudinal traction was then performed with adjunct closed reduction manipulation in valgus position to allow increase of calcaneal height and reduction of varus. Once under live fluoroscopy demonstrated longitudinal distraction across the fracture site, the external fixation device was then locked to maintain length. No traditional extensile lateral or sinus tarsi incisions were utilized in this study, and was performed by a single primary surgeon. A picture is demonstrated in Figure 1 below intra-operatively using the mini-rail as a guide for pin insertion. Figure 2 is a clinical picture of the final mini-rail construct seen in-office. Figure 3 and 4 are postoperative plain films demonstrating appropriate pin placement on the axial and lateral views. As demonstrated on these postoperative films, we were able to achieve appropriate articular posterior facet reduction of the subtalar joint, and regain calcaneal height with varus frontal plane correction.

**Postoperative Care**

Non-weight bearing to the operative extremity for 4 weeks with weekly dressing changes consisting of Betadine to the pin sites, Kerlix, and a loosely applied ACE bandage. Pinsites were cleaned at every visit with isopropyl alcohol to prevent incidence of pinsite infection. At 4 weeks, full protective weight bearing to the extremity with a postoperative shoe at all times. Gentle ankle joint passive range-of-motion exercises were allowed at this point.
The mini-rail external fixation device is removed in office typically at 8 weeks however serial radiographs are used to assess and can be up to 10 weeks until removal.

Assessment

Twenty-one patients were surgically managed for acute calcaneal fracture and also met criteria of minimal one year since procedure date when conducting this research. After institutional review board approval was obtained, all patients were contacted and inquired to participate in this study by fulfilling the American Orthopedic Foot and Ankle Score (AOFAS) questionnaire. AOFAS was the choice of instrumentation in our clinical study to cover pain, function, and alignment including a mixture of questions that are combined objective and subjective in nature to evaluate and properly monitor progress of patients following surgery. This clinical rating system contains three subscales (pain, function, alignment) with a total of nine items. Pain consists of one item with a total of 40 points, which signifies no pain. Function category entails seven items with maximum of 50 points, revealing full function. Lastly, alignment consists of one item with 10 points maximum, indicating good alignment. The total maximum score is 100 points, meaning no impairments or symptoms following procedure. We also inquired if patients were able to return to work, if still following up and if additional surgeries were needed. Of the 21 patients attempted, 12 were accepted to participate in this study and completed the AOFAS questionnaire. Results were recorded, and a final AOFAS score was calculated and analyzed.

Results

Twenty-one patients were evaluated and surgically managed in a 6-year timeframe, 2014 to 2020, who presented to the emergency department with clinical and diagnostic radiographic confirmation of acute, closed calcaneal fractures. From these 21 patients, 12 participated in this study by completing the American Orthopedic Foot and Ankle Score (AOFAS) Questionnaire; all patients had minimum 3-month outpatient postoperative care follow up. Of this population, 8 were male and 4 were female. All calcaneal pathologies were closed without any open disruption of soft tissue envelope, and obtained 3-view plain film foot radiographs for evaluation, as seen in Table 1.

<table>
<thead>
<tr>
<th>Rowe Classification</th>
<th>Number of Patients (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rowe 2B</td>
<td>2 (17%)</td>
</tr>
<tr>
<td>Rowe 3</td>
<td>1 (8%)</td>
</tr>
<tr>
<td>Rowe 4</td>
<td>6 (50%)</td>
</tr>
<tr>
<td>Rowe 5</td>
<td>3 (25%)</td>
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</table>

Table 1 Radiographic plain film Rowe classification of the closed calcaneal fractures.

<table>
<thead>
<tr>
<th>Sanders Classification</th>
<th>Number of Patients (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanders 2A</td>
<td>1 (10%)</td>
</tr>
<tr>
<td>Sanders 2B</td>
<td>2 (20%)</td>
</tr>
<tr>
<td>Sanders 3AB</td>
<td>4 (40%)</td>
</tr>
<tr>
<td>Sanders 4</td>
<td>3 (30%)</td>
</tr>
</tbody>
</table>

Table 2 Computerized tomography radiography Sanders classification of the closed calcaneal fractures.

Computerized tomography (CT) scans were obtained on all but two (10/12, 83%) for detailed fracture identification and surgical planning; the remaining two demonstrated no comminution with single posterior fracture line ‘tongue-type’ fracture. These CT imaging were then classified using Sanders classification, shown in Table 2. A 4-pin monoplanar mini-rail external fixation device was accomplished across the fracture site for fixation and reduction. A minimum of 1 year from procedure date was required for inclusion criteria in this research.

Results of the AOFAS questionnaire are displayed in Table 3. The average AOFAS for our study promoting percutaneous application of mini-rail external fixation received a score of 82.1 One of the three categories of this scoring system is pain, which received an average of 32.5 of total 40 (SD=4.5). The second category function entailed a majority of the AOFAS scoring system containing 7 subcategories. The function category received an average of 40.2 with a possible maximum score of 50, with a range of 13-50 (SD=9.4). The last category of three entailed alignment which received an average of 9.6, total score possible of 10 (SD=1.4). The range of total score was 53-100, with a standard deviation 15.6.
Table 3 AOFAS Hindfoot-Ankle Score. Determined by questionnaire filled out by patient and a physical examination component.

<table>
<thead>
<tr>
<th>Subcategories (Maximum)</th>
<th>Mean</th>
<th>Range</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain (40)</td>
<td>32.5</td>
<td>30-40</td>
<td>4.5</td>
</tr>
<tr>
<td>Function (50)</td>
<td>40.2</td>
<td>13-50</td>
<td>9.4</td>
</tr>
<tr>
<td>Alignment (10)</td>
<td>9.6</td>
<td>5-10</td>
<td>1.4</td>
</tr>
<tr>
<td>Total (100)</td>
<td>82.1</td>
<td>53-100</td>
<td>15.6</td>
</tr>
</tbody>
</table>

Table 4 AOFAS Hindfoot-Ankle Score, Pain category.

Table 4 demonstrates complete results for the pain section of the AOFAS score. 9/12 (75%) of patients rated their pain mild, occasional (+30), where 3/12 (25%) assessed no pain (+40).

Table 5 demonstrates the 7 subcategories for Function (total of 50 points). The first category entailed any limitation of daily activities since the procedure which had a range of 0 to 10 (maximum 10). 10/12 (83%) stated no limitations to daily activities where 2/12 (17%) stated severe. 7/12 (58%) of patients had a maximum walking distance greater than 6 blocks (Max score of 5), 2/12 17% stated 4 block limitation (+4), 2/12 (17%) assessed 1-3 blocks (+2), and 1/12 (8%) stated less than 1 block (+0). 11/12 patients (92%) patients stated no gait abnormalities (max score = 8), where only 1/12 (8%) graded obvious gait abnormality (+4). Regarding ankle hindfoot stability 10/12 (83%) graded maximum stable (+8), however 2/10 (17%) assessed unstable (+0).
<table>
<thead>
<tr>
<th>Function (Activity Limitations/Support Requirements)</th>
<th>Maximum Walking Distance (Blocks)</th>
<th>Walking Surfaces</th>
<th>Gait Abnormality</th>
<th>Sagittal Motion (Flexion Extension)</th>
<th>Hindfoot Motion (Inversion Eversion)</th>
<th>Ankle Hindfoot Stability (Anteroposterior, Varus-Valgus)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>Greater than 6 blocks = 5</td>
<td>No Difficulty on any Surface = 5</td>
<td>None = 8</td>
<td>Normal = 8</td>
<td>Normal = 6</td>
<td>Stable = 8</td>
</tr>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>Four blocks = 4</td>
<td>Some Difficulty = 3</td>
<td>None = 8</td>
<td>Mild Restriction = 4</td>
<td>Moderate = 3</td>
<td>Stable = 8</td>
</tr>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>Four blocks = 4</td>
<td>Some Difficulty = 3</td>
<td>None = 8</td>
<td>Mild Restriction = 4</td>
<td>Moderate = 3</td>
<td>Stable = 8</td>
</tr>
<tr>
<td>Limit of daily/recreational activities = 4</td>
<td>Greater than 6 blocks = 5</td>
<td>No Difficulty on any Surface = 5</td>
<td>None = 8</td>
<td>Mild Restriction = 4</td>
<td>Moderate = 3</td>
<td>Stable = 8</td>
</tr>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>Greater than 6 blocks = 5</td>
<td>No Difficulty on any Surface = 5</td>
<td>None = 8</td>
<td>Normal = 8</td>
<td>Normal = 6</td>
<td>Stable = 8</td>
</tr>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>Greater than 6 blocks = 5</td>
<td>Some Difficulty = 3</td>
<td>None = 8</td>
<td>Normal = 8</td>
<td>Normal = 6</td>
<td>Stable = 8</td>
</tr>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>Greater than 6 blocks = 5</td>
<td>Some Difficulty = 3</td>
<td>None = 8</td>
<td>Normal = 8</td>
<td>Normal = 6</td>
<td>Stable = 8</td>
</tr>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>Greater than 6 blocks = 5</td>
<td>Obvious = 4</td>
<td>Normal = 8</td>
<td>Normal = 6</td>
<td>Stable = 8</td>
<td></td>
</tr>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>Greater than 6 blocks = 5</td>
<td>No Difficulty on any Surface = 5</td>
<td>None = 8</td>
<td>Mild Restriction = 4</td>
<td>Moderate = 3</td>
<td>Stable = 8</td>
</tr>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>Greater than 6 blocks = 5</td>
<td>No Difficulty on any Surface = 5</td>
<td>None = 8</td>
<td>Normal = 8</td>
<td>Normal = 6</td>
<td>Stable = 8</td>
</tr>
<tr>
<td>Severe = 0</td>
<td>Less than 1 block = 0</td>
<td>Severe Difficulty = 0</td>
<td>Obvious = 4</td>
<td>Normal = 8</td>
<td>Normal = 6</td>
<td>Unstable = 0</td>
</tr>
<tr>
<td>Severe = 0</td>
<td>One to Three Blocks = 3</td>
<td>Some Difficulty = 3</td>
<td>None = 8</td>
<td>Severe restriction = 0</td>
<td>Marked restriction = 0</td>
<td>Unstable = 0</td>
</tr>
<tr>
<td>No Limitations of Daily Activities = 10</td>
<td>One to Three Blocks = 2</td>
<td>No Difficulty on any Surface = 5</td>
<td>None = 8</td>
<td>Normal = 8</td>
<td>Normal = 6</td>
<td>Stable = 8</td>
</tr>
</tbody>
</table>

Table 5 AOFAS Hindfoot-Ankle Score, Function category that includes 7 subcategories.
Table 6 AOFAS Hindfoot-Ankle Score, Alignment category.

Table 6 demonstrates the alignment portion of AOFAS score on physical examination. 11/12 (92%) patients demonstrated good, plantigrade foot with hindfoot well aligned, whereas 1/12 (8%) exhibited fair, plantigrade foot with some degree of ankle-hindfoot malalignment.

Additional questions besides the AOFAS score were asked including if patients were able to return to work, if further follow up and additional surgeries were needed (Table 7). 10/12 (83%) patients were able to return to work without limitation, with only 1/12 (8%) unable to return to work. 2 patients (17%) are still following up however with no pain, 1 patient (8%) is still following up with minimum symptoms. Only 1 patient required a secondary surgery.

Table 7 Additional questions.

Discussing

Calcaneal fractures are associated with substantial disability and morbidity with no uniform method to surgically manage, and often debated. The calcaneus contains complex anatomy secondary to its spongy bone structure with thin cortices, these fractures are often associated with high level energy trauma with soft tissue compromise in an avascular angiosome which contributes to the difficulty in handling its fracture. Typically calcaneal fractures are treated by means of open reduction internal fixation via extensile approach and fixation with plate and 3.5mm screws due to good visualization of the fracture at the cost of greater damage to the soft tissue. There is a paradigm shift from the gold standard lateral extensile incisional approach to a minimal invasive approach due to the soft tissue stripping required which carries a high risk of wound dehiscence, soft tissue complications, and infection with published rates of 14-33% [8,11,12]. Soft tissue postoperative complications such as wound breakdown and infection, cellulitis, hematoma formation are widely known for surgical calcaneal fracture ORIF management after full-thickness extensile exposure.
Therefore, secondary to the risk of open surgery with recognized soft tissue complications, this has driven surgeons to seek less traumatic techniques such as minimal invasive surgery to reduce complication rate and tissue damage. Because of this, external fixation, although not entirely novel, have recently gained popularity. Minimal invasive small uniplanar mini-rail external fixation is advantageous in applying skeletal traction and fracture reduction through ligamentotaxis with percutaneous fixation of the posterior facet fragments. We believe this percutaneous method of surgical management can achieve respectable results with fewer complications, better range of motion, less early postoperative pain and higher functional scores of the injured ankle than open surgery.

An essential benefit to this approach, unlike open reduction of calcaneal fracture, is this minimal invasive technique does not require a delay in surgery for edema, and is encouraged before induration and contracture of local soft tissue. In addition, we promote and find this method ideal for patients who are immunocompromised, uncontrolled diabetic, advanced staged neuropathy, multiple comorbidities that are not medically stable who are relatively and possibly absolute contraindicated for open reduction internal fixation [12-14].

In our study, we retrospectively analyzed the outcome for minirail fixation for calcaneal fractures using variables of the AOFAS Ankle-Hindfoot scoring system along with the patient’s ability to return to work, need for further follow-up or additional surgical intervention. We received an AOFAS mean score of 82.1 out of a maximum score of 100, with a 32.5 out of 40 under pain category demonstrating satisfactory results. We direct the success secondary to this procedure being amenable to immediate surgery without delay of soft tissue edema secondary to no incision, with osseous longitudinal traction to restore the height and width therefore reducing fracture. Our intention is to have the minirail fixator as a definitive fixation without the need of secondary surgery, as was performed in this study; however we find the importance to consult the patient that due to the severity of fracture a secondary surgery might be needed. The minirail fixation may be used analogous to a delta frame for distal pilon pathology, ligamentotaxis until soft tissue envelope has resolved within 3-10 days then perform open reduction internal fixation.

Within the AOFAS scoring system, our research found these minirail surgical patients demonstrated a satisfactory Function score of 40.2 of 50. 10/12 (83%) stated no activity limitation or support requirements postoperatively. 7/12 (58%) had no difficulties walking on any surfaces, 4/12 (33%) determined some difficulty on certain surfaces. Also, 11/12 (92%) were able to return to work prior to injury, with only 1/12 (8%) of patients only needing a secondary surgery. These results demonstrated satisfactory results with the ability to perform fragment distraction to achieve distraction with minirail. Regaining length of the calcaneus is essential with this fixation technique by secondarily disimpacting the central fragments of the calcaneus thereby facilitating reduction and fixation.

A malunion complication of a malreduced calcaneal fracture may be debilitating to a patient that alters associated biomechanics of both complex joints, subtalar and midtarsal (Chopart’s) accelerating patient’s post-traumatic osteoarthritis likelihood [1,3,6,7]. A well-known complication of calcaneal fracture is a varus positioned heel which creates abnormal compensatory valgus stress to the ankle joint and midfoot. A shortened migrated heel will influence anterior loading forces of the ankle joint which weakens posterior muscle compartment pull.

**Conclusion**

Degree of displacement with possible comminution, soft tissue envelope condition, subtalar joint incongruence, patient comorbidities such as smoking and diabetic mellitus are important criteria to consider when managing calcaneal fractures which directly influence healing process and can increase surgical complication risk. Surgical management of calcaneal fractures has been proven to have a better quality and function of life after 8-12 years in an operative group versus conservative management, even if end-stage arthrodesis is highly likely due to intra-articular subtalar joint destruction [3,7,9,10]. Although open reduction is a well accepted procedure it does come with many postoperative complications that can be as deteriorating to the patient as the calcaneal fracture itself, such as developing a wound in the surgical site that would require different procedures. Minirail external fixation is a popular choice pertaining to forefoot procedures however not much literally has been published on utilization on rearfoot procedures. This technique allows the surgeon to respect the soft
tissue, immediate intervention to provide calcaneal traction for decompression of fragments, with no risk of surgical skin breakdown or dehiscence. We promote the utilization of mini rail external fixation for calcaneal fractures as this minimal invasive technique does not violate soft tissue, and provides excellent reduction with longitudinal traction with no requirements of secondary surgery.

References


