The Journal of Foot & Ankle Surgery 58 (2019) 755–761

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Fine Wire Circular Fixation for Displaced Intra-Articular Calcaneal Fractures: A Systematic Review

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ARTICLE INFO

Level of Clinical Evidence: 4

Keywords:
calcaneal
circular
fine wire
fracture
Ilizarov

ABSTRACT

Intra-articular calcaneal fractures represent an ongoing challenge for the orthopedic community, with the benefits of the previous "gold standard" treatment of open reduction and internal fixation having been called into question in several large randomized controlled trials. Fine wire circular fixation may represent a useful alternative treatment for these injuries, combining minimally invasive application with rigid fixation, which allows the possibility of early weight bearing We performed a systematic review of published studies that used circular fixation for calcaneal fractures and recorded functional outcomes at follow-up. In a total of 11 studies with 255 calcaneal fractures for which there was follow-up, our inclusion criteria were met: 8.2% of fractures were bilateral, 11.9% of fractures were open fractures, and 12.6% of patients had multiple orthopedic injuries. Functional outcomes were assessed with the use of a variety of tools across the different studies, but outcomes compared favorably with those seen with open reduction and internal fixation. Although pin site infections were common (22.6%), serious complications, including deep infection (0.8%), wound infection (1.6%), and complex regional pain syndrome (0.8%), were exceedingly rare. The results suggest that this is a viable alternative treatment for calcaneal fractures, but higher-quality randomized controlled trials are required before the technique can enter mainstream use.

Intra-articular calcaneal fractures remain a challenging injury for the orthopedic surgeon to treat. They account for 2% of all fractures but tend to represent high-energy injuries sustained by younger patients and have traditionally been associated with disappointing functional outcomes (1). During the past few decades, we have seen changing trends in the management of these injuries, from closed manipulation and casting to percutaneous reduction with Steinmann pins and Kirschner wires to more invasive options for internal fixation. Improvements in anatomic locking plate technologies in the 1990s led to the widespread adoption of open reduction and internal fixation (ORIF) via an extensile lateral approach as the treatment of choice for these injuries, but despite its popularity, the expected improvement in outcomes was not universally achieved, and wound complications were reported in up to 30% of patients in some series (2,3).

A large-scale multicenter randomized controlled trial (RCT) by Buckley et al (4) in 2002 failed to show an overall benefit of ORIF compared with conservative treatment, although subgroup analysis showed a benefit in younger patients, females, and in patients not claiming Workers' Compensation. Likewise, more recent RCTs (5,6) have failed to demonstrate improved patient reported outcomes with open surgery, but they did show higher complication rates. The methodology of these trials can be criticized; for example, Agren et al's (5) study was underpowered and the physical subcomponent of the Short Form 36-Item Health Study failed to reach statistical significance at 8- to 12-year follow-up ($p = .06$). The study did show a 41% risk reduction with ORIF for subtalar osteoarthritis. Griffin et al (6) reported no significant difference, but their study had a short (2-year) follow-up. A recent meta-analysis of RCTs that compared ORIF with conservative treatment (7) concluded that there was insufficient evidence to recommend in favor of either intervention. Based on the subgroup analysis from Buckley et al and studies on patient risk factors for complications, it seems likely that there will be certain patients who are good candidates for ORIF and for whom the potential benefits outweigh the risk. For many other patients, however, alternative treatments need to be found because the outcome of conservative treatment for displaced intra-articular fractures is often disappointing.

Financial Disclosure: None reported.
Conflict of Interest: None reported.
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https://doi.org/10.1053/j.jfas.2018.11.030

The most common complication of open surgery via an extensile lateral approach is wound breakdown, made more likely by the massive soft tissue swelling that often accompanies calcaneal fractures, and by patient factors such as smoking and diabetes (2,3). In light of this issue, interest in less invasive methods of reduction and fixation has increased.

One option involves ORIF via a more limited sinus tarsi approach, which still allows visualization of the posterior facet of the subtalar joint for reduction but provides limited visualization of the lateral wall. Recent meta-analysis data (8) suggest outcomes equivalent to those for ORIF via an extensile lateral approach but with significantly fewer wound complications.

Another option is minimally invasive reduction and percutaneous fixation with Kirschner wires or screws (9). This reduces the risk of wound complications considerably but does so at the expense of rigidity of fixation and requires a very compliant patient group, which is not always the case in calcaneal surgery. A possible alternative could be to use a fine wire circular frame for fixation of the calcaneum after minimally invasive reduction. This apparatus combines the benefit of percutaneous application with fixation strong enough to allow early or even immediate weightbearing.

Many articles discuss the technique and demonstrate the use of fine wire circular fixators with Ilizarov principles for calcaneal fractures (10–24), but the concept has not yet gained widespread acceptance. The purposes of this review are to present current evidence for this technique and to discuss whether the technique warrants further investigation.

Materials and Methods

The authors performed searches of the English-language literature on the electronic journal databases MEDLINE, EMBASE, PubMed, AMED, CINAHL, Cochrane Library, and World Health Organization Intentional Clinical Trials Registry, up to July 2018. Search terms used were “calcaneal” OR “calcaneus” AND “Ilizarov” OR “fixator” OR “frame” OR “external fixation” OR “circular” OR “ring.”

All articles found were screened by the authors and included if they met previously agreed criteria: (1) acute treatment of displaced intra-articular calcaneal fractures, (2) use of a fine wire ring fixator as definitive treatment, (3) patient reported functional outcome data included in the results, and (4) patients >17 years old. Extra-articular fractures of the tuberosity and delayed reconstructions (>6 weeks after injury) were excluded.

Technique guides, individual case reports, and case series lacking outcome data were excluded from the data analysis but were used to inform the subsequent discussion. Studies using other forms of external fixation and those using external fixation as a temporary measure before definitive ORIF were excluded.

For studies that met the inclusion criteria, 2 authors independently extracted the following information: authors, year of publication, total number of patients and number of calcaneal fractures, number of bilateral fractures and concomitant orthopedic injuries, number of open fractures, and Sanders grade of the fractures. The exact method of fixation in terms of pattern of rings used and method for reduction and fixation of the posterior facet of the subtalar joint were recorded. Finally, outcomes including functional scores, radiographic indices, heel and subtalar pain, and any complications were recorded. Any discrepancies in the information extraction between authors were reviewed again, and consensus agreement was met. Where the level of detail presented in the original articles permitted it, results were pooled to give cumulative results.

The quality of the original studies and risk of bias were assessed by using the Hawker checklist.

Results

Database searches identified 659 articles; we screened 90 abstracts and the full text of 32 articles. Eleven articles were found to meet the inclusion criteria (14–24) for our data analysis (Fig. 1)—10 case series (14–23) and a single-cohort study (24). When consolidated, the studies included a total of 255 calcaneal fractures with follow-up data available, including 21 bilateral fractures. Where reported, 46.6% were Sanders grade 3 and 23.9% were Sanders 4. In addition, 12.6% had multiple orthopedic injuries and 11.9% were open fractures (Table 1).

Unsurprisingly the precise surgical technique and frame construct varied among the studies. All frames used a foot-plate or half-ring for passing wires through the calcaneum itself, and the majority (9 of 11) of studies connected this to a 2-ring block on the distal tibia (Fig. 2). One study used a single ring for fixation to the tibia, and another had no fixation above the ankle joint. Six of 11 studies achieved further fixation with wires placed into the forefoot (Table 2).

Restoration of the shape and overall alignment of the hindfoot were achieved via traction/distraction and closed manipulation in all studies; in 5 studies, a temporary traction device separate from the actual frame was used to achieve this.

Distraction and ligamentotaxis will aid in the reduction of the subtalar joint fragments but could not always achieve anatomic reduction. The displaced fragments of the posterior facet were accessed and reduced via a small lateral incision distal to the lateral malleolus in 7 studies, which generally allowed direct visualization of the posterior facet as it was reduced. No author described any difficulties in closing the skin in this area. Instead, in 2 studies, percutaneous reduction of the posterior facet was performed under radiological control via a small stab incision in the plantar aspect of the heel. Bone graft or substitute was used in at least 78 (33.2%) cases.

To maintain the reduction of the posterior facet, in 6 of 11 studies, Ilizarov wires were used through this area; in 1 study, the frame was supplemented with percutaneous screws beneath the posterior facet; and in 2 studies, a Schanz pin was used directed from posterior. In 2 series, no fixation of the posterior facet was used; instead, the authors relied on the frame to offload and protect that area from distracting forces.

The duration that the frame was left in situ ranged from 6 weeks to 3 months. Immediate weightbearing was permitted in the majority (6 of 11) of studies; in 2 additional studies, weightbearing commenced in the third and fourth postoperative weeks. Follow-up time ranged from 5 months to 7 years, with a mean of 28.1 months.

A variety of outcome measures were used in the different studies. The American Orthopaedic Foot and Ankle Society (AOFAS) and Maryland scores were used in the majority, with the Academy of Ambulatory Foot and Ankle Surgery and Creighton-Nebraska scores used once each. Two authors used their own functional scoring systems. The variety in scoring systems makes it difficult to directly compare the different techniques but, overall, 43.1% of patients were reported as having “excellent” outcomes and 43.1% of patients were reported as having “good” outcomes according to the specific scoring system, where this descriptive measure was given. Where reported, mean AOFAS scores ranged from 66 to 88.2, with a cumulative mean of 77.5 (Table 3).

Subtalar joint range of motion was reported in 7 studies, and 81% of patients retained at least 25% motion relative to the uninjured side. Ongoing moderate or severe subtalar joint pain was reported in 36.7% of fractures, in the 5 studies that commented on it, and radiographic evidence of subtalar arthritis was seen in 44%. Ongoing heel pad pain was present in just 3.6% of patients.

Heel width and the overall conformation of the foot generally appear to be well restored with circular fixation, as the mean Bohler’s angle after frame removal ranged from 16.3° to 33.8° in 6 studies (cumulative mean 24.8°), and just 13.9% of patients required altered footwear or orthotics after treatment.

Complications were recorded in all studies, the most common of which by far was superficial pin site infection. Where the precise number of pin site infections is actually reported, 22.6% of patients had at least 1 infection. However, the vast majority of pin site infections responded readily to oral antibiotics, and deep infection is reported in only 2 (0.8%) patients. Only (1.6%, all from a single series) 4 patients developed infections around the wound used to reduce the subtalar joint, and only 4 patients developed an area of superficial skin necrosis. Other complications included collapse of the reduction of the subtalar joint in 2 patients and chronic regional pain syndrome in an additional 2 patients.

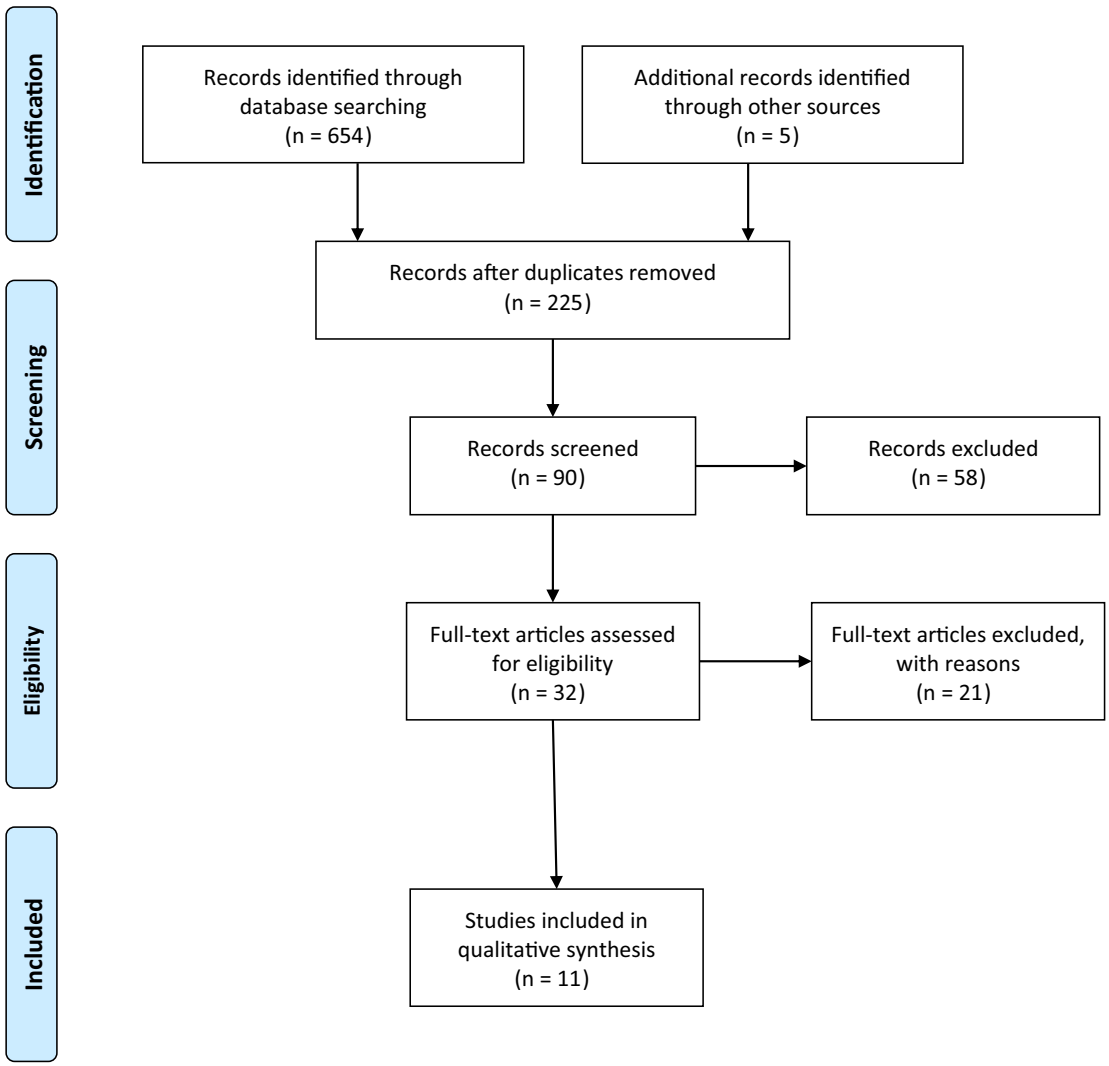

Fig. 1. Flowchart of study searches.

Discussion

The number of published articles that we located demonstrates the international interest in using fine wire circular fixation for calcaneal fractures. When considered together, the series included in our review suggest that this technique could produce outcomes for patients at least as good as those seen with ORIF but with a much reduced rate of serious complications. Further outcome data in published conference abstracts tends to agree with this suggestion (25). By comparison, in RCTs looking at the treatment of closed, isolated calcaneal fractures, functional outcomes after ORIF included a mean AOFAS score of 75.5 in a study by Agren et al (5) in a group that contained only 12% comminuted Sanders

Table 1
Injury characteristics (N = 255)

First author	Year	Follow-up for fracture (n)	Length of follow-up	Sanders grade 3 (n)	Sanders 4 (n)	Bilateral (n)	Other fractures (n)	Open fractures (n)
Pescatori	1989	7	Mean 16.7 months			0	0	
Paley	1993	8	2 to 4 years			1	0	
Schwartsman	2002	44	Mean 19 months	27	17	6	7	2
Talarico	2004	25	2 to 7 years	6	2	2	0	
Emara	2005	12	Mean 20 months	12	0	0	0	4
Polyzois	2005	36	Mean 2.5 years	22	2	2	2	
McGarvey	2006	20 (of 33)	Mean 25 months	8	9	2	20	11
Ali	2009	25	Mean 30 months	9	6	0	0	2
Mauffrey	2009	15	Mean 25 months			0	7	2
Osman	2009	15 (of 16)	12 months	4	10	0	0	
El-Mofawi	2017	48	Mean 44.9 months	23	11	8	0	0

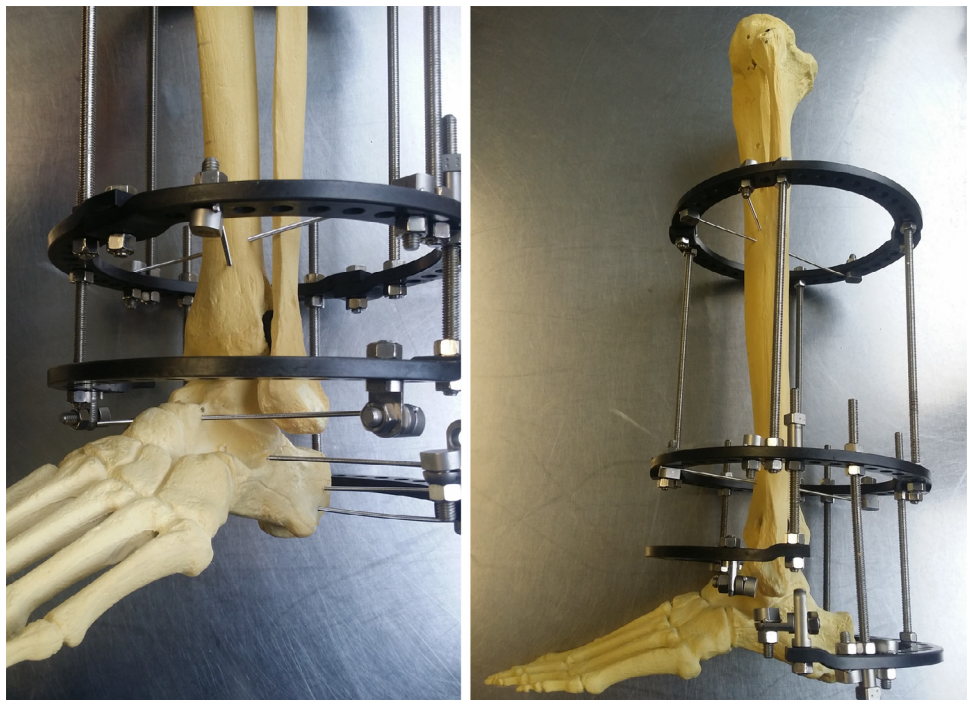

Fig. 2. Model of typical frame configuration.

4 fractures and a mean AOFAS score of 79.2 in a study by Griffin et al (6). Complication rates after ORIF in these studies included surgical site infections in 19% to 21% and an 11% reoperation rate to remove prominent or infected metalwork.

There is some variability in the outcomes reported in the articles that we analyzed, but to an extent this can be explained by patient selection. In a number of the studies, patients were selected for Ilizarov fixation precisely because they had open fractures or severe soft tissue injuries around the calcaneum or because they had multiple orthopedic injuries. It is generally agreed that these patients would be expected to have a poorer outcome, and indeed they would have been excluded from all of the major RCTs looking at the efficacy of ORIF.

In the only cohort study comparing Ilizarov fixation with ORIF (24), patients were treated with a circular frame only if their skin condition was too poor for ORIF, thus creating a bias in favor of internal fixation. Despite this, outcomes were comparable, with fewer complications in the Ilizarov group.

McGarvey et al (19) reported the worst overall outcomes (mean AOFAS score 66) of all the series of circular fixation, but of the 31 patients in their series, 11 had open fractures, an additional 4 had severe fracture blisters that precluded ORIF, 2 had bilateral fractures, and 23 had multiple orthopedic and systemic injuries. With such a challenging patient group, one might expect slow functional recovery, and, indeed, when those patients with a follow-up of <10 months were excluded, the mean AOFAS scores rose to 74. In the few patients who were treated with isolated, closed calcaneal fractures, the mean score was 77. This highlights the failure of scoring systems to accommodate for disability caused by concomitant injuries.

All authors reported that they were able to achieve near anatomic reduction of the posterior facet of the subtalar joint, with gross loss of reduction rarely seen (1.6%) during the time the frame is in situ. We know from studies of ORIF that the reduction is not always as accurate as surgeons might think intraoperatively, but in the 2 studies (15,24) where a follow-up computed tomographic scan was used after removal of the frame, 94% of patients maintained anatomic reduction. In comparison, after ORIF, reduction with <2-mm articular incongruity was achieved in 57% to 78% of patients in recent RCTs (3,4).

It is generally considered that anatomic reduction of the joint surface is one of the key requirements for good outcomes in calcaneal fractures, but it is equally recognized that poor outcomes can be seen even

Table 2
Frame characteristics (N = 255)

First author	Year	Rings on tibia (n)	Forefoot wires	Exposure of subtalar joint	Fixation of subtalar joint	Weightbearing in frame	Frame duration
Pescatori	1989	0	No	Nil, reduced by traction	None	Full	2 to 4 months
Paley	1993	2	Yes	Lateral incision	Screw ± 1 wire	Full	9 to 11 weeks (mean 10)
Schwartsman	2002	2	No	Through sole	1 Wire	Partial to full	8 weeks
Talarico	2004	2	No	Lateral incision	Wire in 20, screw in 5	Full	5 to 9 weeks (mean 6.6)
Emara	2005	2	Yes	Lateral incision	None	Non	3 months
Polyzois	2005	2	No	Lateral incision	2 wires	Full	6 to 9 weeks (mean 6.8)
McGarvey	2006	2	Yes	Through sole	1 wire	Full	12 weeks
Ali	2009	2	Yes	Lateral incision	1 or 2 wires	Partial from week 3	8 to 12 weeks (mean 9.7)
Mauffrey	2009	1	Yes	Posterolateral incision	1 Wire	Non	26 to 95 days (mean 54)
Osman	2009	2	No	Lateral incision	Posterior Schanz pin	Non	8 to 12 weeks (mean 9.1)
El-Mofawi	2017	2	Yes	Posterior Schanz pin	Posterior Schanz pin	FWB from week 4	8 to 12 weeks (mean 10.5)

Table 3
Patient outcomes and complications (N = 255)

First author	Fractures (N)	Scoring system	Functional outcome (n)	Bohler's angle (°)	Pin site infections	Wound infections
Pescatori	7	Authors'	Excellent in 4, good in 2	20.1	0	0
Paley	8	Authors'	Excellent in 5, good in 2		1	0
Schwartsman	44	Maryland	Excellent in 30, good in 14		"Occasional"	0
Talarico	25	Maryland	Excellent in 8, good in 15		5	0
Emara	12	AOFAS	Mean 88.2	33.75	2	0
Polyzois	36	Maryland	Excellent in 8, good in 20		5	0
McGarvey	20	AOFAS	Mean 66		9	1 deep
Ali	25	AOFAS	Mean 68, excellent in 6, good in 11	24	"Most"	0
Mauffrey	15	AAFAS	Mean 80	16.28	3	1 deep
Osman	15	Maryland	Excellent in 8, good in 5		10	4 superficial
El-Mofawi	48	AOFAS	84.6	26.3	7	0

Abbreviations: AAFAS, Academy of Ambulatory Foot and Ankle Surgery; AOFAS, American Orthopaedic Foot and Ankle Society.

with good radiological reduction, and this may be due in part to the severity of damage to the articular cartilage of the subtalar joint at the time of fracture. This is an area where circular fixation may offer an advantage over internal fixation, as the frame allows for controlled distraction of the subtalar joint during the healing process. It remains debatable whether this unloading of the joint encourages chondrocytes to regenerate the hyaline cartilage matrix of the articular surface or whether repair with fibrocartilage is more likely. Regardless of which mechanism is occurring, case series of distraction arthroplasty for post-traumatic ankle osteoarthritis (26,27) report a reduction in pain after treatment, with 1 report (26) also demonstrating an average improvement in AOFAS scores of 19 points. It is reasonable to believe that the articular cartilage of the subtalar joint could respond in a similar way, and subtalar joint distraction was used intraoperatively in 8 of the studies in our review, with 2 studies reporting an increase in the distraction at subsequent follow-up appointments.

Circular frame fixation appears to be able to restore overall height, width, and alignment of the calcaneum, which may in itself improve function (28). In patients who do go on to develop subtalar arthritis, this improved alignment may also simplify and improve the outcome of subsequent subtalar joint fusion, in much the same way that outcomes of fusion are improved if the anatomy has previously been restored through ORIF (29).

Another potential benefit of Ilizarov fixation is that it allows for early full weightbearing postoperatively. A number of series have described early partial weightbearing after calcaneal ORIF (30,31), with the earliest allowing protected weightbearing from a mean of 4.8 weeks postoperatively (30), but none have permitted immediate full weightbearing. It should be noted that compliance with weightbearing restrictions has never been continuously monitored in any study on calcaneal fractures, and recent studies after other foot and ankle operations showed poor compliance with non-weightbearing and partial weightbearing instructions (32–34). Treatment in a frame, therefore, would remove the concern that patients could overload their fixation and displace the fracture, and it may facilitate earlier postoperative mobilization and discharge. This is particularly pertinent in patients with bilateral fractures (35) or patients with other musculoskeletal injuries (36) and could potentially confer economic benefits in certain healthcare systems.

The versatility of Ilizarov frame fixation confers an extra benefit in the polytraumatized patient, where the frame can be extended to treat ipsilateral lower limb injuries (36).

It is also worth noting that complex regional pain syndrome and chronic heel pad pain potentially contribute to morbidity in patients after calcaneal fractures, and it is thought that early simulation of the heel through weightbearing could reduce the incidence of these complications (15). Both of these conditions were rarely seen in our review, with complex regional pain syndrome being reported in just 0.8% of patients across all case series and heel pad pain noted in 3.6% of patients in series that reported on this. It is interesting, therefore, that in 3 of the 11 series included in our review, patients were kept strictly non-weightbearing for the duration of frame treatment, thus neglecting this potential benefit.

Regarding complications seen with Ilizarov fixation of calcaneal fractures, it must be accepted that superficial pin tract infections are commonly seen, as they are in other areas where these frames are used. The vast majority of these infections settle readily with oral antibiotic treatment, but removal of the affected wire and replacement in a separate location can be used in more resistant infections. Deep infections were rarely seen (0.8%) and in both cases were due to traumatic soft tissue injuries rather than infected wire sites. Infections of the wound through which reduction of the subtalar joint was performed were seen in 1.6%, but superficial skin breakdown in this area was reported in just 1 case. Certainly these rates compare favorably to those reported in studies on ORIF of calcaneal fractures, particularly considering the poor soft tissue condition of many of the patients treated with Ilizarov fixation.

Ankle range of motion was not assessed postoperatively in most studies, but a potential concern with frame fixation would be the development of ankle stiffness if a patient was immobilized in a frame for several months. The only 2 studies which that assessed ankle range of motion at follow-up found full or "almost full" movement in 69 of 73 patients. Two other studies (14,37) sought to avoid this issue by proposing the use of frames constructed entirely below the level of the ankle joint, with wires placed through the talus and midfoot instead of the tibia. An alternative could be to incorporate a hinge at the level of the ankle joint into the frame.

It is interesting to note that neurovascular injury was not reported in any of the 255 patients in our review. This is particularly surprising as a number of cadaveric studies have highlighted the risk of injury to nerves and vessels with the passage of wires or pins, particularly through the medial aspect of the calcaneus (38–43). Wires passing beneath the posterior facet of the subtalar joint risk injury to the tibial nerve or its branches and to the posterior tibial artery and vein, and wires passing farther posterior in the tuberosity may threaten the medial calcaneal nerve. Paley and Fischgrund (15) describe a technique of intrafocal wire insertion through the sustentaculum tali fragment to reduce the risk of neurovascular injury. On the lateral aspect of the calcaneus, the calcaneal branches of the sural nerve may be injured, but these have been suggested to have lesser clinical importance (43). A recent review found a 2.8% incidence of neurovascular injury after calcaneal ORIF (44); this is certainly something that should be commented on specifically in future studies on calcaneal circular fixation.

It must be noted that fine wire circular fixation is a technically demanding procedure that requires specialist training. This would likely limit the widespread use of the technique for fixation of large numbers

of calcaneal fractures. There have been reports of the use of simple pin-to-bar monolateral (45–48) or bilateral (49–53) external fixators for stabilization of the calcaneus, either as a temporizing measure before definitive ORIF (47,48,50) or as a definitive treatment (45,46,49–53). The application of these fixators is less complex, and most orthopedic surgeons will have experience in using them for other lower limb fractures. Where a monolateral frame was used before definitive ORIF, there is a suggestion that recovery of soft tissue swelling occurs more rapidly, allowing earlier ORIF (47), but benefits in terms of long-term outcome compared with standard ORIF have not been investigated.

Where pin-to-bar fixators are used as definitive treatment, they appear to be able to restore the alignment of the hindfoot, with postoperative Bohler's angle values close to those seen with circular fixation (45,46,48). Like the circular fixators, they achieve reduction via ligamentotaxis, and supplemental reduction and internal fixation may be required to improve the reduction of the subtalar joint. The major difference with circular fixators is that monolateral or bilateral fixators have significantly less bending rigidity to loading. Although gross loss of reduction was not reported in any of the series of monolateral or bilateral fixators, patients were instructed to remain strictly non-weightbearing for the duration of the frame in most series. Two studies did allow early weightbearing at 28 (51) and 30 days (46) postoperatively.

Pin-to-bar fixators are certainly an option where expertise in circular fine wire fixation is not available, but they confer the risk of similar complications without being able to deliver some of the theoretical benefits. The clinical impact of these differences remains to be seen, as promising outcomes have been seen in some studies of external fixators in patients with less comminuted calcaneal fractures (45,46,49).

Certainly there are limitations to this review, principally due to the low quality of currently published studies. All except 1 study lack any form of comparator group, and the lack of explicit inclusion criteria or randomization in any of the studies allows the possibility of selection bias. The variability in the choice of outcomes reported and the loss of a significant number of patients to follow-up in 1 study could introduce reporting bias. Follow-up times are limited, which may lead to an underestimation of late complications such as subtalar arthritis and the need for subtalar fusion. Due to the lack of subgroup outcome data in any of the studies, it was unfortunately not possible to separate outcomes for open versus closed fractures. Only 1 study subdivided outcomes for different Sanders grades of fracture (17), and this showed significantly worse outcomes in Sanders grade IV fractures than in Sanders grade II or III fractures.

The outcomes across the studies are surely encouraging for the use of this technique. The concept of obtaining solid fixation with minimal surgical insult to the already traumatized soft tissues is certainly attractive. It must be remembered, however, that early case series of ORIF for calcaneal fractures also reported very positive results, and it was only when more rigorous RCTs were performed that the limitations of that technique were exposed.

At this point, it seems unlikely that any single operation can be offered as a universal solution for all calcaneal fractures. Instead, each case must be assessed individually, taking into account characteristics of the patient, the calcaneal fracture, and other associated injuries. Some patients will be candidates for ORIF, either via an extensile lateral approach or via the less invasive sinus tarsi approach. Other patients will still be most suitable for a nonoperative treatment, as the "least bad" alternative. Minimally invasive forms of fixation, including fine wire circular fixation, must also have a role in the armamentarium.

From the results presented in this review, it can be concluded that circular fixation is a viable alternative for the treatment of calcaneal fractures and would logically be particularly applicable in cases of polytrauma and severe soft tissue injury. The focus of future research should be on discerning which subgroups of closed, isolated calcaneal fractures would benefit more from this versus other forms of fixation. This determination requires higher-quality, randomized studies with validated patient-reported outcome measures and adequate power and follow-up.

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