

Less Invasive Treatment of 265 Intraarticular Calcaneal Fractures with An Interlocking Nail (C-nail)

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Submitted: 26 Aug 2021; Accepted: 03 Sept 2021; Published: 10 Sept 2021

Citation: Martin Pompach, Martin Carda, Marek Peme, David Prchal, Michael Amlang and Hans Zwipp (2021) Less Invasive Treatment of 265 Intraarticular Calcaneal Fractures with An Interlocking Nail (C-nail). *Int J Ortho Res*, 4(3): 85-93.

Abstract

Objectives: Less invasive restoration of joint congruity and calcaneal shape in displaced intra-articular calcaneal fractures via a sinus tarsi approach followed by minimally invasive internal fixation with an interlocking nail (C-nail) results in a low rate of soft-tissue complications and good outcomes.

Design: Prospective case-control study.

Setting: Regional Hospital Trauma Department

Patients: A total of 265 calcaneal fractures were treated by using the C-nail between 2011 and 2018 at the Department of Traumatology at the Regional Hospital Pardubice.

Intervention: The reduced joint surface was fixed with one or two screws with short thread. All other fragments were fixed after reduction with the C-Nail introduced through the tuberosity. The fragments were fixed with 7 interlocking screws passing through the nail.

Main Outcome Measures: Patients were assessed for complications, restoration of Böhler angle, posterior facet reduction with postoperative computed tomography, and weight-bearing radiographs after 6 and 12 months.

Results: Wound edge necrosis was seen in three cases (1.1%) and soft tissue infection was observed in one case (0.4%). Böhler's angle was improved from 5.9° preoperatively to 32.1° postoperatively, measuring 27.6° after 12 months.

Conclusions: Two hundred forty-nine patients (222 males and 27 females; mean age 47.3 years) with 265 calcaneal fractures were treated between 2011 and 2018 less-invasively. The sinus tarsi-approach with use of the C-nail shows low risk of infection due to high stability of the fixed fracture.

Keywords: Calcaneal Fracture, Sinus Tarsi Approach, Locking Calcaneal Nail, Open Calcaneal Fractures

Introduction

The C-nail is an implant that allows for less-invasive osteosynthesis of a calcaneal fracture, used together with 6-7 interlocking screws inserted into the nail using the guiding device to provide high stability to the primarily reduced fracture fragments (Figure 1) [1-6]. Contrary to the conventional lateral extensile technique, the sinus tarsi approach is less invasive allowing reduction of the posterior calcaneal facet without detaching a huge flap from the bone [7-9]. The standard practice in calcaneal surgery has been to use the extended lateral approach with a locking plate to fix the fracture fragments [10-14]. However, several associated complications are reported with these methods—a higher risk (~20.1%) of superficial soft-tissue infection, hematoma requiring evacuation (4.7%), wound-edge necrosis (15%), deep soft-tissue infections (13.6%), or even a 9% chance of developing osteomyelitis of the calcaneus and sepsis from chronic osteomyelitis necessitating calcanectomy [10, 12, 14-16]. To mitigate these complications, eventually, percutaneous screw-fixation alone or insertion using the minimally-invasive sinus tarsi approach were performed which resulted in lower biomechanical stability [17, 18]. Furthermore, superficial pin infections (7%) and deep bone infections (1.7%) have been reported with percutaneous Kirschner-wire-fixation [19]. Therefore, a combination of a less-invasive approach, the sinus-tarsi approach, and a biomechanically stable implant, the C-nail fixation, was employed to improve the stability of the osteosynthesis and substantially reduce the risk of complications [1, 3-6].



Figure 1: C-nail aiming device with three arms (sustentacular, superior, lateral) and the central fixed C-nail having a length of 65 mm, a diameter of 8 mm, and 7 options for locking screws. Two screws are guided by the sustentacular arm into the sustentacular fragment, two by the superior arm into the tuberosity fragment, and 2-3 screws are guided by the lateral arm into the tuberosity fragment and the main anterior process fragment.

Methods

Patient data

Two-hundred forty-nine patients with two-hundred sixty-five calcaneal fractures treated using C-nail at the Department of Traumatology, Regional Hospital, Pardubice, Czech Republic, between 2011 to 2018 were included in this study. All calcaneal fractures

were classified using CT examination according to Sander's classification into types I, IIA, IIB, IIC, IIIAB, IIIAC, IIIBC, and IV [20]. The study cohort also included patients with open calcaneal fractures (Table 1) [21]. Patients with a history of smoking were also included in the study with special instructions to stop smoking until the wound has healed. Likewise, those with well-controlled diabetes mellitus type I/II were also included. Children with open calcaneal apophysis, patients with short calcaneus less than 65 mm in length, patients with poorly controlled diabetes mellitus, severe vasculopathy, manifestations of immunodeficiency, or poor compliance (drug abuse and psychiatric conditions) were excluded from the study.

Table 1: Main characteristics of 249 patients with 265 intra-articular calcaneal fractures treated with sinus tarsi approach and C-nail. Variables are expressed as mean ± standard deviation or frequency and percentage (%).

Variable	Mean ± standard deviation, Frequency and percentage (%)		
Age (years)	47.3 ± 12.9		
Sex	Male	222	89.2
	Female	27	10.8
Sanders classification	I	18	6.8
	II A	95	35.8
	II B	53	20.0
	II C	16	6.0
	III AB	37	14.0
	III AC	12	4.5
	III BC	12	4.5
	IV	22	8.3
Gustilo & Anderson classification	o I	1	0.4
	o II	3	1.1
	o IIIa	1	0.4
	o IIIb	1	0.4
Tscherne & Oestern classification	c 0	112	42.3
	c I	136	51.3
	c II	11	4.2
Bilateral calcaneal fracture	Yes	16	6.4
	No	233	93.6
Cigarette smoker	Yes	120	45.3
	No	129	48.7
Diabetes mellitus	Yes	21	8.6
	No	228	93.1

C-nail: Implant properties

A stainless-steel C-nail, 65 mm long and 8 mm in diameter, was used. The nail is available in right and left versions and the length

is extendable by using different endcaps (5, 10, 15, and 20 mm). Using an aiming device with 3 arms (sustentacular, lateral, superior), 3.5 mm cortical screws with a flat head can be guided perfectly into the nail. With the sustentacular arm, 2 screws are guided into the sustentaculum, 2 other screws hit the tuberosity fragment using the superior arm, and with the lateral arm, 2-3 screws are guided into the tuberosity as well as the anterior-process main fragments. In this study, an endcap was used in all cases to avoid bone ingrowth into the nail and ensure better conditions for nail-removal.

Indications

All types of Sanders classification I, IIA, IIB, IIC, IIIAB, IIIAC, IIIBC, and IV are indicated for C-nailing. Open calcaneal fractures classified as Gustilo-Anderson I, II, and III were also included not excluded (n=6). The timing of surgery was determined based on the soft-tissue condition and open fractures were debrided immediately and nailed later similar to the closed fractures. A fracture-dislocation with high displacement of the fragments was treated as an emergency to avoid compartment syndrome and skin necrosis. Overall, a closed fracture with blunt soft tissue injury could be operated on within the first two days after trauma, while those arriving late to the hospital with severe edema or even bullae were delayed to allow edema resolution and skin healing (Figures 2a, 2b). One of the open calcaneal fractures (Gustilo-Anderson oIIIa) occurred from a high-energy fall from height as fracture-dislocation, with signs of compartment syndrome and a 1 cm open wound on the medial side, which can be visualized indirectly as the air bubbles in the CT-scan (Figures 2a, 2b) [21]. The most severe case of a Gustilo-Anderson type-oIIIb with extensive soft tissue injury and fragment exposure is shown in Figures 3a, b, and c.



Figure 2: (a) Example of a severely displaced intraarticular fracture-dislocation with a 1cm long open wound at the medial side, indirectly seen by the air bubbles in the soft tissues. The fracture was classified as Sanders type IIA, Gustilo-Anderson-II, and clinically severe due to high pressure in the soft tissues by hematoma and severely displaced fragments, with an additional compartment syndrome, the lateral posterior facet fragment was driven off by the tip of the lateral malleolus (red arrow). After immediate debridement, reduction, and C-nailing (b) the soft tissue recovered rapidly and healed uneventfully, also medially. (c) The postoperative CT-scan shows the 1 mm step-off on the reduced posterior facet and small abrasion at the sustentaculum tali.

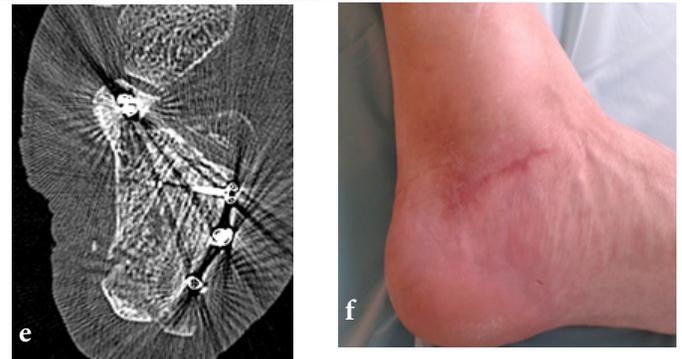


Figure 3: Example of an open Gustilo-Anderson IIIb calcaneal

fracture in a 52-years old male after a fall from the ladder (a) shows a medial 5 cm long wound. The lateral CT scan (b) demonstrates the tilted tongue type fracture with air in the subtalar joint. The axial CT-scan (c) defines a Sanders IIA type. The postoperative lateral and axial CT scans (d,e) show an anatomic reduction of the subtalar joint and regained normal Böhler's angle. (f) Secondary healed wound on the medial side.

Contraindications

The calcaneal length was measured radiologically, especially important in the case of short patients, where patients with a small calcaneus (< 65 mm) were contraindicated. Other contraindications were beak fractures (fracture at the level of entry-point of the nail), children with open calcaneal apophysis, infected soft tissue, poorly controlled diabetes mellitus, manifestations of neuropathy including Charcot's arthropathy, severe vasculopathy, manifestations of immunodeficiency, or poor compliance by the patient (drug abuse and psychiatric conditions).

Remark: Additional 126 calcaneal fractures (during the same period, from 2011 to 2018), were treated nonoperative in our trauma unit because, either they did not require surgery or surgery was contraindicated (as mentioned above). Therefore, these cases were not analyzed in this study.

Surgical Technique

Only two surgeons who are the authors of this study performed surgery.

Approach

The sinus tarsi approach starts just below the tip of the lateral malleolus (landmark one) and runs for about 3 cm into the direction of the fifth metatarsal base (second landmark). This allowed for anatomic reconstruction of the subtalar joint in all cases.

Reduction

A distraction device greatly facilitates the reduction of the tuberosity fragment toward the sustentacular fragment, which is crucial to maintain both the hindfoot axis and the calcaneal height. Therefore, two Schanz screws are needed. The first 6 mm Schanz screw is positioned laterally into the distal tibia and the second into the lateral side of the calcaneal tuberosity fragment. The distraction device is then attached, and the desired calcaneal height and length can be achieved step-by-step (Figure 4, see Video, Supplemental Digital Content 1). This distracting maneuver helps reduce the fragments of the posterior articular surface from the medial to the lateral side. As soon as the subtalar joint is anatomically reduced and the Böhler's angle is regained, the fragments are temporarily fixed with Kirschner wires ensuring no hindrance to the nail positioning. The congruency of the subtalar joint facet is checked fluoroscopically using Broden projections. Definitive fixation of the posterior facet is achieved (under fluoroscopic guidance in axial projection) using two 4.0 cancellous screws with short thread, which lie close and beneath the posterior articular surface running into the sustentaculum (Figure 5).



Figure 4: For the calcaneal distraction device, a Schanz screw is inserted into the tuberosity of the calcaneus and another one into the distal tibia both laterally. The length and height of the displaced calcaneus, its axis, and pitch can be corrected by extension. Also, reduction of the posterior facet fragments becomes much easier by this maneuver.



Figure 5: The correct insertion of two 4.0 mm single screws with short thread. Screws are placed close under the posterior facet after anatomic reduction of its 2-3 fragments requiring fluoroscopic visualization in the axial view. The well-aligned tuberosity is temporarily fixed with two K-wires towards the talus each far laterally and medially not to hinder the introduction of the nail. Before the nailing, the distraction device is removed.

Supplemental Digital Content

1 Distraction device, video 1,



Insertion of the C-nail

A short horizontal incision of 10-15 mm is made just below the Achilles tendon insertion. The guidewire is then placed centrally, within the calcaneal body but slightly more lateral than central, ascending to the mid of the height of the calcaneocuboid-joint and the guide wire is stopped just 5 mm before the calcaneocuboid-joint border. The correct positioning of this guidewire has to be checked fluoroscopically in the lateral and dorsoplantar projection and the

calcaneus is reamed. The nail is attached to the guiding device with the three arms (Figure 6) and then inserted by mild turning movements into the calcaneus. Then, the first guiding wire is directed through the sleeve, which is pushed into one of the two holes of the guiding device's sustentacular arm. The appropriate position of the first guidewire, whether hitting the correct position in the sustentaculum, is checked in the axial plain fluoroscopically, following which, the second wire can be placed only if the first is correct. If not, the wire is withdrawn and the nail, together with the aiming arms, has to be rotated, and the wire is drilled again guided into the sustentaculum. When both guide wires are placed correctly (as seen on fluoroscopy), the first guiding wire can be substituted by an interlocking screw after guided drilling and measuring. The second sustentacular screw and two superior screws, as well as at least two lateral screws, are then easily inserted using the correct positioned skin incisions.



Figure 6: After wire-guided reaming, the C-nail which is fixed to the aiming device is now inserted below the Achilles tendon insertion between the two Kirschner-wires into the calcaneus. The locking screws are now placed under the guidance of the first sustentacular arm, then by the superior, and at least by the lateral arm.

Usually, the middle lateral hole stays empty to avoid peroneal tendon damage. Lastly, the end cap is attached to the end of the nail. The operation is finished by fluoroscopy in four plains (lateral, axil, Broden, dorsoplantar), followed by placing the suction drain and soft tissue sutures (Figure 2b).

Postoperative Management

A standardized postoperative plan was followed for all patients, wherein suction drainage was removed at the postoperative day-2 and low-molecular-weight heparin was prescribed for a month to prevent deep vein thrombosis. Only elastic bandages and no plaster fixation were done for all patients. Active exercises of the ankle and subtalar joint were initiated from the second day after surgery. On average, the patients were discharged from the hospital on the fifth postoperative day (range=3-63 days). Non-weight bearing exercises at home were advised and avoid bearing weight on the operated limb for 8 weeks. Bone healing and assessment of

intra-articular surface were quantified by evaluating x-ray and CT scans. The functional outcome was assessed the earliest 12 months postoperative with the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale.

Results

The 249 patients with 265 calcaneal fractures undergoing surgery were aged between 17-73 years (mean = 47.3 ± 12.9 years), of which 45.3% were smokers and 8.6% of the patients had well-controlled diabetes mellitus type I/II. Based on the CT-examination, the fractures belonged to Sander's type I (n=18), IIA (n=95), IIB (n=53), IIC (n=16), IIIAB (n=37), IIIAC (n=12), IIIBC (n=12), and IV (n=22). Six patients with open calcaneal fractures (2.3%) were also included in the study cohort. Table 1 presents the demographic and baseline clinical characteristics of all 249 patients with 265 calcaneal fractures.

The less-invasive sinus tarsi approach healed with only 3 incidents of wound-edge necrosis (1.1%) and just 1 (0.4%) patient developed an infection in the whole cohort (Table 2). The average preoperative Böhler's angle, as measured in lateral radiographs, was $5.9^\circ \pm 11.6$ (range= -58° to 40°), which changed to a mean of $32.1^\circ \pm 7.2$ (range= 15° to 40°) immediately postoperative. After one year, a slight decrease in the Böhler's angle, mean = $27.6^\circ \pm 7.4$ (range= 15° to 40°), was measured. On the CT examination, the average posterior facet step-off as measured preoperatively was $5.6 \text{ mm} \pm 4.8$ (0mm – 30 mm), while the postoperative average was $0.7 \pm 1.4 \text{ mm}$ (0 mm – 10 mm) (Figure 7a-e, see Video, Supplemental Digital Content 2). The average AOFAS score was calculated as 90.5 ± 8.19 (75–100) points at 1-year follow-up.

Post-traumatic arthritis in the subtalar joint was seen in six cases (2.3%) during the 8-year follow-up, but only one (0.4%) required subtalar arthrodesis due to severe pain. The range of motion of the hindfoot at 1-year follow up was completely normal (100% compared to the uninjured side) in 27% of patients, slightly limited (76-100% of the normal) in 38% of patients, partially limited (50-75% of normal) in 32% of patients, and limited (< 50% of normal) in 3%. Sural nerve damage was not observed in any case. Wound edge necrosis was seen in three cases 1.1%. The only patient who developed a deep infection (Staphylococcus aureus found at the wound site) had sustained a beak fracture and the infection started at the entry point of the nail (Table 3). The C-nail was removed, followed by repeated wound debridement, vacuum drainage, and intravenous and local antibiotic treatment. After 2 weeks of debridement and vacuum drainage, a polymethylmethacrylate (PMMA) antibiotic-loaded cement spacer was inserted into the defect. The wound healed spontaneously after secondary wound closure. Therefore, after that negative experience we decided to include beak fractures into the group of contraindications. Lastly, only 6 (2.3%) cases required C-nail removal, of which 1 had developed deep infection, four patients had local hindfoot pain, and the sixth was removed on the patient's request.

Table 2: The measurements in 265 cases of intraarticular calcaneal fractures show the mean Böhler’s angles preoperatively, postoperatively, and one year after surgery, ranging from an initial improvement of 26.2° to a mild mean decrease of 4.5° after one year. Additional CT scans show average values and ranges of the posterior facet step off before and after surgery and that the improvement due to surgery was an average of 4.9 mm.

	Average	SD	Min.	Max.
Böhler’s angle (preoperative)	5.9°	± 11.6	-58°	40°
Böhler’s angle (postoperative)	32.1°	± 7.2	15°	40°
Böhler’s angle (12 months)	27.6°	± 7.4	15°	40°
Articular step-off (preoperative)	5.6 mm	± 4.8	0 mm	30 mm
Articular step-off (postoperative)	0.7 mm	± 1.4	0 mm	10 mm

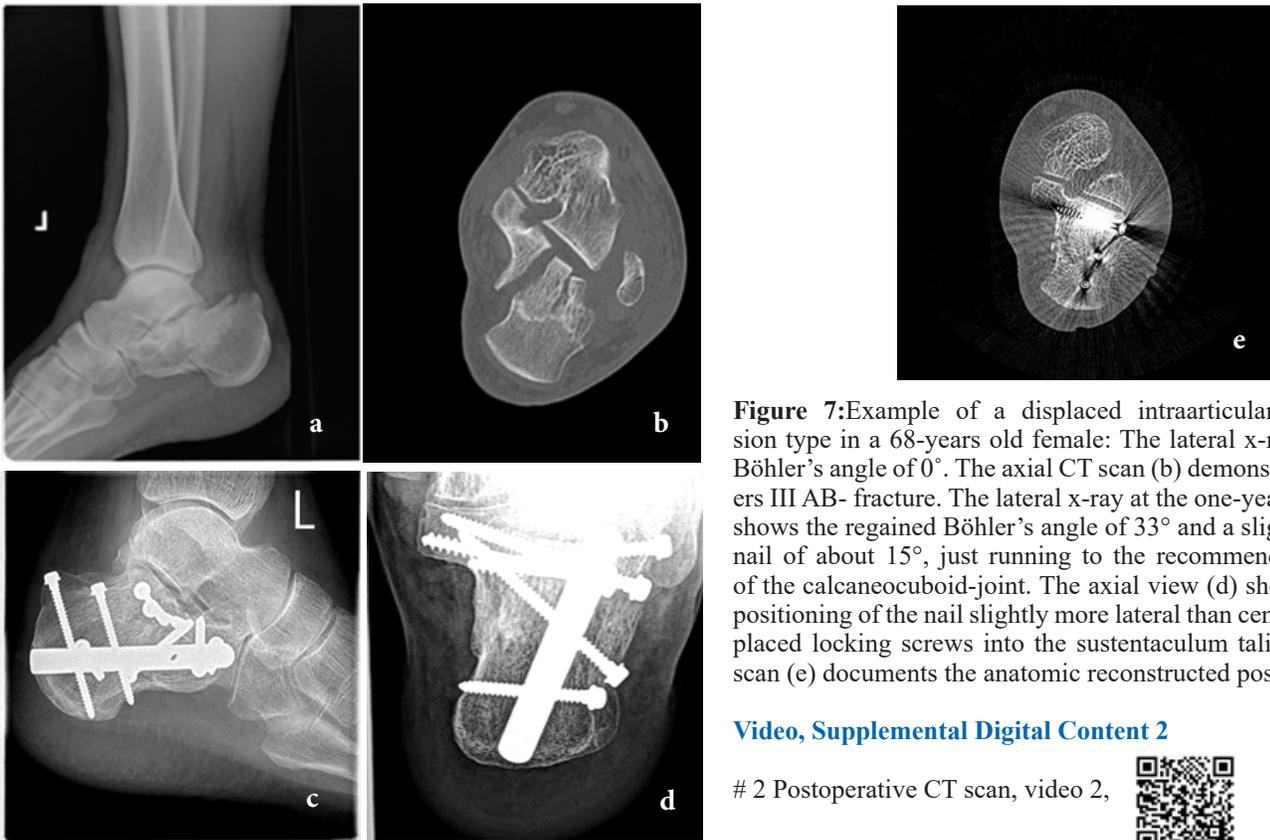


Figure 7:Example of a displaced intraarticular joint depression type in a 68-years old female: The lateral x-ray (a) shows a Böhler’s angle of 0°. The axial CT scan (b) demonstrates the Sanders III AB- fracture. The lateral x-ray at the one-year follow-up (c) shows the regained Böhler’s angle of 33° and a slightly ascending nail of about 15°, just running to the recommended half-height of the calcaneocuboid-joint. The axial view (d) shows the correct positioning of the nail slightly more lateral than central; the ideally placed locking screws into the sustentaculum tali. The axial CT scan (e) documents the anatomic reconstructed posterior facet.

Video, Supplemental Digital Content 2

2 Postoperative CT scan, video 2,



Table 3: Early and late complications, and functional scores reported in previous studies of >100 patients using the extended lateral approach and plate fixation of an intraarticular calcaneal fracture, in comparison to the 265 cases of sinus tarsi approach and C-nail osteosynthesis (*)

Author	n	Follow – up (years)	Wound edge necrosis %	Infection %	Subtalar arthrodesis %	Sural nerve lesion %	Results	Score
Bezes (1993)[28]	205	3.3	10	2.4	2.7	No data	85 % good/ exc.	No data
Zwipp (1993)[29]	123	3	8.3	1.9	3.3	No data	61 % good/ exc.	Zwipp
Naovaratnophas (2001)[30]	114	6.8	13.3	2.6	No data	No data	84/100	Creighton-Nebraska
Park (2000)[31]	103	2.4	3.9	0	1.0	No data	90 % good/ exc.	AOFAS
Rammelt (2003)[22]	168	1.5	7.8	6.1	5.8	No data	80.8	AOFAS
Rammelt (2013)[14]	149	7.9	14.7	5.4	6.0	No data	72.6	AOFAS
Sanders (2014)[13]	108	10-20	11	0.9	29	6.5	75	AOFAS
Pompach et al.* (2021)	265	1-8	1.1	0.4	0.4	0	90.5	AOFAS

*Results of this study

Discussion

The less-invasive sinus tarsi approach, combined with the interlocking C-nail osteosynthesis, is well tolerated by patients, evident as improved average AOFAS scores on 1-year follow-up. Strikingly, there were very few incidents of complications, like superficial wound healing problems, one case of deep infection rate, no sural neuritis, and only 1 patient out of 265 requiring subtalar fusion, since we began using the novel implant and treatment approach in 2011.

Sanders et al. presented long-term (10-20 years follow-up) results of 108 cases treated with extended lateral approach and plate fixation, of which 11% had wound-edge necrosis, 0.9% developed an infection, 6.5% of patients developed sural neuritis, while 29% of the patients required subtalar arthrodesis [13]. Likewise, Rammelt et al. in a 7.9-years follow-up of 149 cases reported wound edge necrosis (14.7%), infection (5.4%), and subtalar arthrodesis (6.0%) as frequent complications with the conventional technique [14]. Some short-term follow-up reports, with a smaller sample size, of the extended lateral approach with plate fixation have also described superficial soft tissue infection of 19.7%, deep soft tissue infections in 13.6%, or even osteomyelitis of the calcaneus in 9% of patients [11, 12, 15]. The incidence of postoperative hematoma requiring revision after an extended lateral approach was reported up to 5%, compared to none in our study with a considerably larger sample size. Similarly, in a smaller study with 45 patients subjected to the extended lateral approach with plate fixation, 9 patients (20%) experienced hypersensitivity around the scar, and 5

patients needed subtalar fusion (11%) within a comparable study period, whereas we did not observe any such findings in our 265 patients having a sinus-tarsi scar [22, 23]. Only one of the 265 cases has required subtalar fusion to date. In a recent study, Zeman et al. compared the extended lateral approach with locking compression plate fracture fixation in 217 patients and a smaller group of 19 patients undergoing C-nail osteosynthesis using a sinus tarsi approach [24].

They observed almost comparable AOFAS scores and improvement in Böhler’s angle in both groups, but the LCP group had more incidents of deep infection (1.9%) compared to none with C-nailing. They concluded that C-nail should be the first choice for treating Sanders’s type II and III fractures. Radomskii et al. developed a Ukrainian calcaneal nail similar to the C-nail used in this study and used it in 29 calcaneal fractures [25]. The nail has only three holes for locking screws versus seven holes of the C-nail. They achieved an average AOFAS score of 83.7 points in 12 months, with no reports of infections. However, retrocalcaneal pain was reported in 5 of the 29 cases (17%), urging them to remove the nail after fracture healing, compared to 6 of 265 patients (1.5%) in our study, of which only 4 had heel pain. Simon et al. in 2015 presented a study with 63 patients about a so-called ‘French-Nail or Calca-Nail’, with a 12 mm diameter, having the option for two locking screws to reduce the broken posterior facet [26].

At 12.3-months follow-up of 54 patients, ten had already undergone a subtalar fusion, 6 primarily and 4 secondarily within

the first 12 months, equivalent to a subtalar fusion rate of 18.5% within the first year after trauma. Whereas in our study with 265 C-nails, no patient needed a primary fusion, and only one patient (0.4%) required secondary fusion after 8 years. Our Czech-German group using the C-Nail at three centers recorded data from a large sample of 106 C-nailing monitored between 2011 and 2013 [1]. These primary data showed an improvement in Böhler's angle from an average of 7.3° preoperatively to 31.2° postoperatively and 28.7° after one year. Two of the 106 cases (1.9%) had superficial wound edge necrosis and only one patient had an open fracture with deep infection (0.9%). The AOFAS scoring correlated to 92.6 after one year. These results were comparable to Veliceasa et al. who presented a report of 75 cases of C-nailing and showed a similarly low incidence of wound edge necrosis (4%), superficial infection (1.3%), and no deep infection. The AOFAS score was 90.2 after 12 months. Steinhausen et al. presented a comparative retrospective study between C-nail and locking calcaneal plate, where 92 patients with 101 calcaneal fractures (C-nail n=52, plate n=49) were evaluated [4, 27]. The authors reported significant faster weight-bearing and bone healing in patients treated with C-nail in compare to calcaneal plate. Further, it was shown, that patients of the plate subgroup developed more often subtalar arthroses and suffered more often with wound edge necrosis. Finally, to evaluate the biomechanics and stability after plating or nailing a standardized calcaneus fracture in a human cadaveric specimen, Reinhardt et al. compared three implants - the C-Nail (Medin, Czech Republic), the Calcanail (FH Orthopedics, Heimsbrunn, France), and the Rimbus locking plate (Intercus, Rudolstadt, Germany) [5]. This biomechanical study also corroborated that the C-Nail was more stable than the interlocking Rimbus-Plate and much more stable than the French Calcanail [28-31].

Conclusion

This study efficiently demonstrates the benefits of nailing over plating in calcaneal fractures, as comparable AOFAS-Scores can be obtained but with fewer wound healing problems. This is ensured by the biomechanical stability of the nail with a locking system in three planes supplemented by a minimally-invasive approach for fracture reduction and stabilization. The sinus tarsi approach also safeguards the patient from sural nerve problems, guaranteeing their satisfaction. Although only a few open fractures were included; however, none showed a higher risk of infection and the need for special flapping. The low rates of infection despite the inclusion of heavy smokers and diabetic patients encourages C-nailing in risk patients as well as in the elderly. The long-term results at 10 years show some requirement for a secondary subtalar fusion; however, the procedure can still be regarded superior to the extended lateral approach and plate fixation because it can be performed in Sanders types, in fracture-dislocations, and both closed and open calcaneal fractures. The only contraindications are beak fractures, pediatric fractures, or those with a short calcaneus.

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