

Functional and Radiological Outcomes of Minimally Invasive Sinus Tarsi Approach for Closed, Displaced Intra-Articular Calcaneal Fractures: A Prospective Clinical Study

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Received: 01-06-2026 / Revised: 15-07-2026 / Accepted: 21-08-2026

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Conflict of interest: Nil

Abstract

Background: Displaced intra-articular calcaneal fractures are challenging injuries in which restoration of calcaneal morphology and subtalar congruity is essential for functional recovery. The sinus tarsi approach provides limited lateral exposure while potentially reducing soft-tissue morbidity.

Objectives: This study evaluated the functional, radiological and postoperative outcomes following minimally invasive sinus tarsi approach fixation of displaced intra-articular calcaneal fractures.

Methods: A prospective hospital-based study was conducted between October 2024 and September 2025 involving 30 adults with closed, displaced intra-articular calcaneal fractures (Sanders II–IV) treated with open reduction and internal fixation through a sinus tarsi approach. Functional outcome was assessed using the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Score. Radiological parameters included Böhler's angle, Gissane's angle, calcaneal height and width. Time to radiological union, full weight-bearing, return to work, subtalar range of motion and postoperative complications were also evaluated.

Results: The mean age was 39.60 ± 10.57 years, with males comprising 83.3% of the cohort. Falls from height were the predominant mechanism (73.3%). Böhler's angle improved significantly from $9.79 \pm 3.27^\circ$ preoperatively to $28.65 \pm 2.26^\circ$ postoperatively ($p < 0.001$), while Gissane's angle improved from $127.00 \pm 4.19^\circ$ to $121.20 \pm 1.61^\circ$ ($p < 0.001$). Calcaneal height increased and width decreased following fixation. Mean radiological union occurred at 11.03 ± 1.97 weeks. The mean AOFAS score was 81.27 ± 14.89 , with 80% of patients achieving good or excellent outcomes. Full weight-bearing was achieved at a mean of 9.63 ± 1.77 weeks and return to work at 3.54 ± 1.21 months. Wound-related complications occurred in 10% of patients, with no deep infection or reoperation.

Conclusion: Minimally invasive sinus tarsi fixation was associated with satisfactory restoration of calcaneal morphology, favourable functional recovery and a limited frequency of wound complications in appropriately selected displaced intra-articular calcaneal fractures. Larger comparative studies with longer follow-up are warranted.

Keywords: Calcaneal fracture; Intra-articular fracture; Sinus tarsi approach; Minimally invasive surgery; Open reduction and internal fixation; Böhler's angle; AOFAS score; Hindfoot.

DOI: 10.25258/ijcpr.18.9.150

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Introduction

Calcaneal fractures are among the most challenging injuries of the hindfoot, with displaced intra-articular calcaneal fractures (DIACFs) carrying particular clinical significance because of disruption of the posterior facet and loss of normal calcaneal morphology. Alteration of calcaneal height, width and alignment can impair subtalar mechanics and load transmission, contributing to

persistent pain, stiffness, gait disturbance and post-traumatic subtalar arthritis. Consequently, treatment is directed not only towards fracture union but also towards restoration of articular congruity and hindfoot anatomy to optimise long-term function [1,2]. Operative management of appropriately selected DIACFs aims to restore the posterior facet and re-establish calcaneal

morphology. The extensile lateral approach (ELA) has traditionally facilitated broad exposure for reduction and internal fixation; however, extensive soft-tissue dissection may increase the risk of wound dehiscence, infection and other soft-tissue complications. These concerns have encouraged increasing use of less invasive approaches that seek to achieve adequate fracture reduction while limiting disruption of the vulnerable lateral soft-tissue envelope [3,4]. Importantly, the choice of surgical approach represents a balance between sufficient visualisation for reduction and minimisation of approach-related morbidity [1,2].

The sinus tarsi approach (STA) provides targeted access to the posterior facet through a smaller lateral incision and has emerged as an alternative to extensile exposure. Comparative evidence generally indicates that STA can achieve functional and radiological outcomes comparable to ELA, with several studies reporting lower wound-complication rates [5-7]. More recent pooled evidence similarly demonstrates greater wound-related morbidity with ELA while finding no significant differences between approaches in final Böhler angle, Gissane angle or calcaneal dimensions [8]. Nevertheless, findings have not been entirely uniform; some analyses and long-term comparative studies have reported no significant differences in selected complications or clinical and radiological outcomes between the two approaches [9,10]. Early prospective CT-based evidence also demonstrated that the sinus tarsi approach can permit satisfactory reduction and stable fixation through limited exposure [11]. Thus, current evidence supports STA as a viable minimally invasive approach rather than establishing universal superiority across all clinical endpoints and fracture patterns.

Against this background, assessment of STA should extend beyond the technical achievement of fracture reduction to encompass the relationship between restoration of calcaneal anatomy, functional recovery and postoperative morbidity. Prospective evaluation of these complementary outcomes is particularly relevant because treatment success in DIACFs is multidimensional and may be influenced by fracture severity, patient characteristics, surgical technique and postoperative recovery. The present study therefore evaluated radiological restoration alongside functional outcome and postoperative recovery in patients undergoing minimally invasive STA fixation. This study aimed to evaluate the functional and radiological outcomes, postoperative recovery and complications following minimally invasive sinus tarsi approach fixation of closed, displaced intra-articular calcaneal fractures.

Materials and Methods

Study design and setting: A prospective hospital-based study was conducted in the Department of Orthopaedics, Silchar Medical College and Hospital, Assam, between October 2024 and September 2025. The study included 30 adult patients with closed, displaced, intra-articular fractures of the calcaneum treated with open reduction and internal fixation (ORIF) through a sinus tarsi approach.

Participants: Patients aged ≥ 18 years with closed, displaced intra-articular calcaneal fractures presenting within three weeks of injury were eligible. Fractures with >2 mm displacement and Sanders type II–IV morphology were included. Patients with open or extra-articular fractures, established union, major systemic comorbidities, pre-existing foot or ankle deformity, contraindications to elective surgery, or inability/unwillingness to complete follow-up were excluded.

The sample size was calculated using Daniel's formula, yielding approximately 30 participants, who were selected from eligible patients using simple random sampling. Written informed consent was obtained from all participants, and institutional ethical approval was secured before study initiation.

Preoperative Assessment: All patients underwent clinical and radiological assessment before surgery. Plain radiographs of the affected calcaneum were obtained, supplemented by computed tomography for fracture characterization and Sanders classification. Preoperative radiological assessment included Böhler's angle, Gissane's angle, calcaneal height and calcaneal width. Routine preoperative investigations were performed to assess fitness for surgery.

Surgical Technique: All fractures were treated by ORIF through the sinus tarsi approach under spinal or general anaesthesia with intraoperative C-arm fluoroscopy. Patients were positioned laterally, and a limited 4–5 cm incision was made inferior to the lateral malleolus toward the base of the fourth metatarsal. The sinus tarsi and posterior facet were exposed through limited soft-tissue dissection.

Reduction involved restoration of the sustentacular fragment, correction of calcaneal height and varus deformity, and elevation of the posterior facet to restore subtalar congruity. Reduction was provisionally maintained with K-wires and definitive fixation was achieved using cannulated cancellous screws and/or a lateral calcaneal plate according to fracture configuration. Wounds were irrigated, haemostasis achieved and closure performed in layers. Figure 1 representative intraoperative image for sinus tarsi approach.



Figure 1: Representative intraoperative image for sinus trasi approach.

Postoperative protocol and follow-up:

Postoperatively, patients received standardized wound care, analgesia and limb elevation. Wounds were inspected during the early postoperative period, with suture removal generally at 12–14 days. Ankle and subtalar range-of-motion exercises were initiated during the first postoperative week.

Patients remained non-weight-bearing for approximately six weeks, followed by progressive weight-bearing according to clinical and radiological healing. Follow-up assessments were performed at 2, 6, 9 and 12 weeks and subsequently at three-month intervals up to one year. Figure 2 represented as Post-operative follow up.

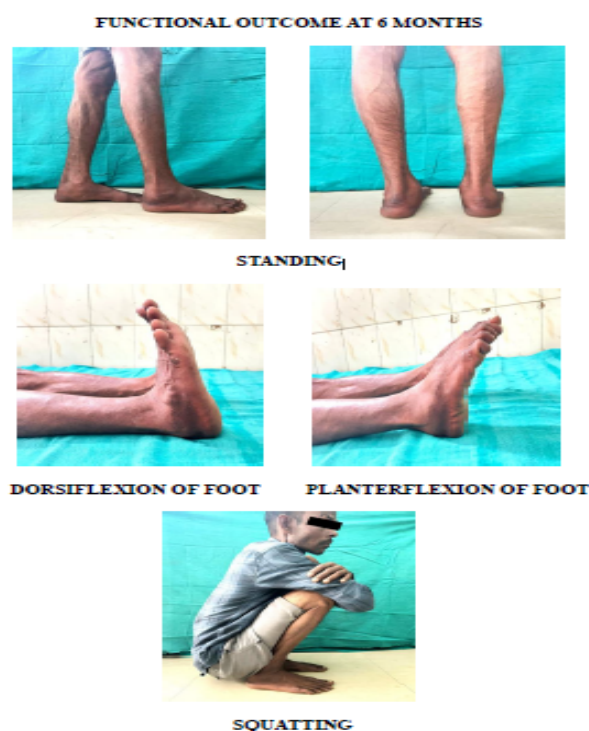


Figure 2: Post-operative follow up

Outcome Measures: The primary outcome was functional recovery assessed using the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Score. Secondary outcomes included radiological restoration of Böhler's angle, Gissane's angle, calcaneal height and width; time to radiological union; subtalar range of motion; time to full weight-bearing; return to work; operative duration; and postoperative complications.

Complications including wound infection, wound dehiscence, implant failure, nerve injury and joint stiffness were documented during follow-up.

Statistical Analysis: Data were compiled and coded in Microsoft Excel and analysed using SPSS version 21.0. Categorical variables were summarized as frequencies and percentages, while continuous variables were expressed as mean $\pm$ standard deviation. The chi-square test was used for categorical associations, and the paired *t*-test was

used for preoperative–postoperative comparisons. The thesis also employed one-way ANOVA for comparison of AOFAS scores across Sanders fracture groups and correlation analysis for the relationship between postoperative Böhler's angle and AOFAS score. A *p*-value <0.05 was considered statistically significant.

Results

Thirty patients who fulfilled the eligibility criteria underwent ORIF through the sinus tarsi approach and were included in the final analysis. The mean age was 39.60 ± 10.57 years (range, 20–60 years), with males comprising 25 (83.3%) patients. A fall from height was the predominant mechanism of injury (73.3%), followed by road traffic accidents (20.0%) and industrial accidents (6.7%). Right-sided fractures accounted for 53.3% of cases and left-sided fractures for 46.7%. Sanders type II fractures were most frequent (40.0%), followed by type III (33.3%) and type IV (26.7%) (Table 1).

Table 1: Baseline demographic and fracture characteristics of the study cohort (n = 30)

Characteristic	Category	n (%)
Age, years	Mean $\pm$ SD	39.60 ± 10.57
	Range	20–60
Sex	Male	25 (83.3)
	Female	5 (16.7)
Mechanism of injury	Fall from height	22 (73.3)
	Road traffic accident	6 (20.0)
	Industrial accident	2 (6.7)
Side involved	Right	16 (53.3)
	Left	14 (46.7)
Sanders classification	Type II	12 (40.0)
	Type III	10 (33.3)
	Type IV	8 (26.7)

Values are presented as n (%) unless otherwise indicated.

Radiological Outcomes: Substantial restoration of calcaneal morphology was observed following fixation through the sinus tarsi approach (Table 2). The mean Böhler's angle increased from $9.79 \pm 3.27^\circ$ preoperatively to $28.65 \pm 2.26^\circ$ postoperatively, representing a mean correction of 18.86° ($p < 0.001$). The mean Gissane's angle

decreased from $127.00 \pm 4.19^\circ$ to $121.20 \pm 1.61^\circ$, with a mean correction of 5.80° ($p < 0.001$). Calcaneal dimensions also demonstrated restoration of morphology, with mean height increasing from 35.08 ± 1.09 mm to 41.57 ± 1.44 mm and mean width decreasing from 47.59 ± 1.46 mm to 36.83 ± 1.47 mm.

Table 2: Preoperative and postoperative radiological parameters

Radiological parameter	Preoperative, mean $\pm$ SD	Postoperative, mean $\pm$ SD	<i>p</i> value
Böhler's angle ($^\circ$)	9.79 ± 3.27	28.65 ± 2.26	<0.001
Gissane's angle ($^\circ$)	127.00 ± 4.19	121.20 ± 1.61	<0.001
Calcaneal height (mm)	35.08 ± 1.09	41.57 ± 1.44	NR*
Calcaneal width (mm)	47.59 ± 1.46	36.83 ± 1.47	NR*

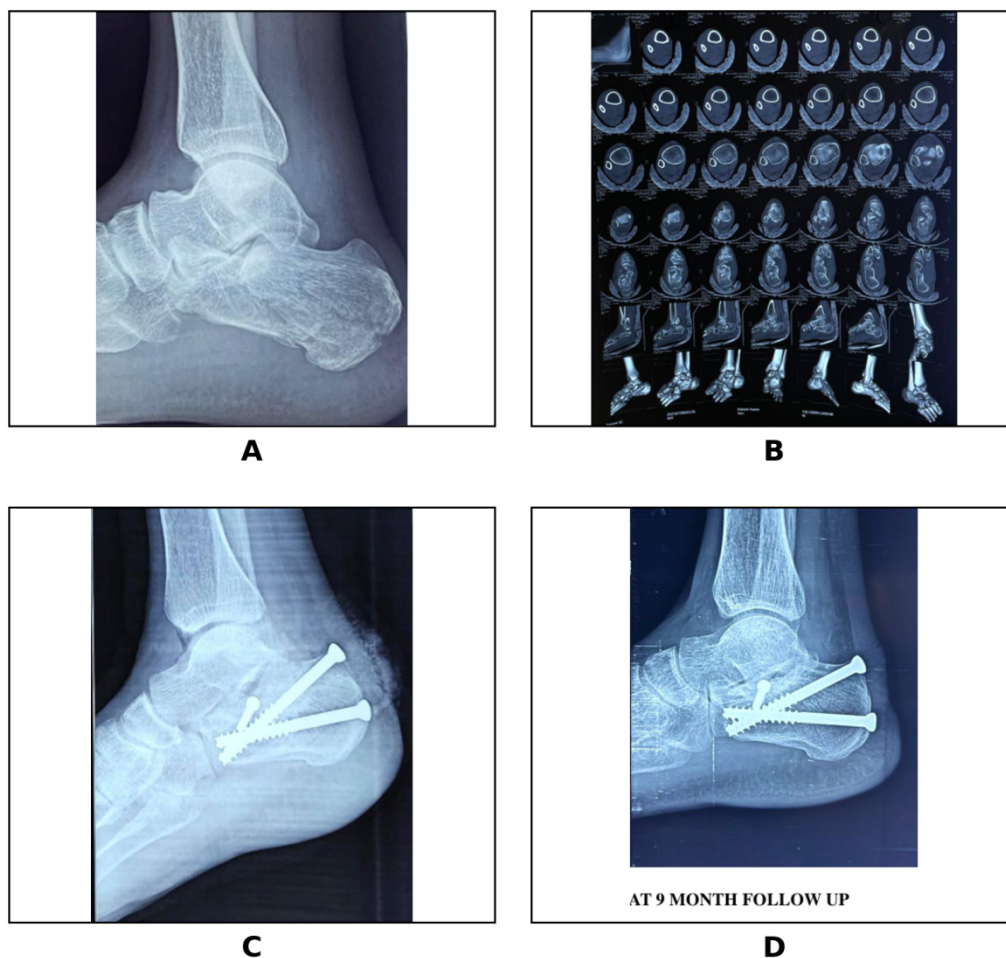


Figure 3: Representative radiological assessment of a displaced intra-articular calcaneal fracture treated through the sinus tarsi approach. (A) Preoperative lateral radiograph; (B) preoperative computed tomography demonstrating the intra-articular fracture pattern; (C) immediate postoperative radiograph following reduction and fixation; and (D) follow-up radiograph demonstrating maintained reduction and fracture union.

Radiological union was achieved in all patients at a mean of 11.03 ± 1.97 weeks (range, 8–14 weeks), with most fractures demonstrating union between 10 and 12 weeks.

Functional and recovery outcomes: Functional recovery was favourable overall (Table 3). The

mean postoperative AOFAS Ankle-Hindfoot Score was 81.27 ± 14.89 (range, 40–99).

Excellent outcomes were observed in 33.3%, good in 46.7%, fair in 13.3%, and poor in 6.7%, resulting in 80.0% of patients achieving excellent or good outcomes.

Table 3: Functional and postoperative recovery outcomes

Outcome	Result
AOFAS score	81.27 ± 14.89
Range	40–99
AOFAS category	
Excellent	10 (33.3%)
Good	14 (46.7%)
Fair	4 (13.3%)
Poor	2 (6.7%)
Excellent + good	24 (80.0%)
Subtalar range of motion	
Full	10 (33.3%)

Mild restriction	14 (46.7%)
Moderate restriction	5 (16.7%)
Severe restriction	1 (3.3%)
Radiological union	11.03 ± 1.97 weeks
Range	8–14 weeks
Full weight-bearing	9.63 ± 1.77 weeks
Range	8–14 weeks
Return to work	3.54 ± 1.21 months
Range	2.0–6.5 months
Returned to work ≤ 5 months	26 (86.7%)

Continuous variables are presented as mean $\pm$ SD unless otherwise indicated.

Subtalar motion was fully preserved in 33.3% of patients, while 46.7% had mild, 16.7% moderate and 3.3% severe restriction. Full weight-bearing was achieved at a mean of 9.63 ± 1.77 weeks, with

66.6% of patients achieving full weight-bearing by 9 weeks. The mean time to return to work was 3.54 ± 1.21 months, and 86.7% had resumed work within five months.

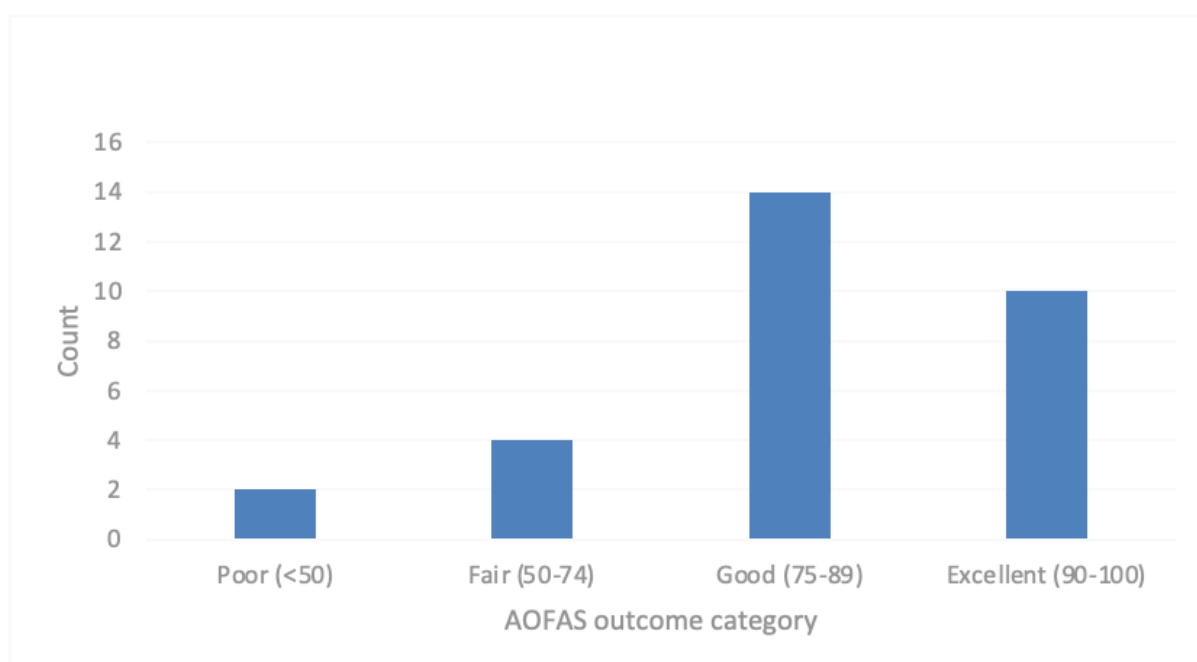


Figure 4: Distribution of functional outcomes according to AOFAS score

Figure 4: Functional outcome distribution according to the AOFAS Ankle-Hindfoot Score.

Excellent and good outcomes were observed in 33.3% and 46.7% of patients, respectively, while fair and poor outcomes occurred in 13.3% and 6.7%.

Postoperative complications: Three patients (10.0%) developed postoperative wound

complications (Table 4). These comprised two cases of superficial infection (6.7%) and one case of wound dehiscence (3.3%). No deep infection or reoperation was reported. The distribution of wound complications across Sanders fracture categories was not statistically significant ($\chi^2 = 3.509$, $p = 0.476$).

Table 4: Postoperative wound complications

Complication	n (%)
No wound complication	27 (90.0)
Superficial infection	2 (6.7)
Wound dehiscence	1 (3.3)
Any wound complication	3 (10.0)
Deep infection	0
Reoperation	0

Secondary Analyses: Final functional outcome did not differ significantly according to Sanders fracture severity. Mean AOFAS scores were 83.92 ± 15.91 for Sanders II, 76.60 ± 14.64 for Sanders III and 83.13 ± 14.07 for Sanders IV fractures. One-way ANOVA demonstrated no significant between-group difference ($F = 0.730$, $p = 0.491$).

The relationship between postoperative radiological restoration and functional outcome was further explored using postoperative Böhler's angle and AOFAS score.

A weak, non-significant negative correlation was observed (Pearson's $r = -0.065$, $p = 0.734$; $n = 30$).

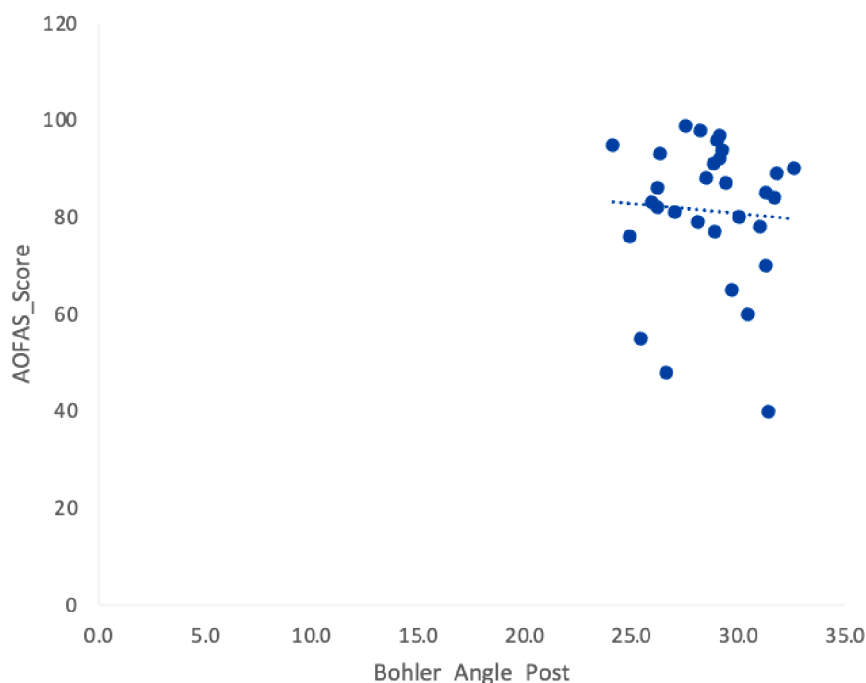


Figure 5. Correlation between postoperative Böhler's angle and AOFAS score

Figure 5. Relationship between postoperative Böhler's angle and functional outcome. No significant linear correlation was observed between postoperative Böhler's angle and AOFAS Ankle-Hindfoot Score (Pearson's $r = -0.065$, $p = 0.734$; $n = 30$).

Discussion

Principal findings: The present prospective study evaluated 30 patients with closed, displaced intra-articular calcaneal fractures treated using open reduction and internal fixation through a minimally invasive sinus tarsi approach (STA).

The principal finding was substantial restoration of calcaneal morphology, demonstrated by significant improvement in Böhler's and Gissane's angles together with restoration of calcaneal height and width. Functional recovery was generally favourable, with a mean AOFAS hindfoot score of 81.27 ± 14.89 and 80% of patients achieving good or excellent outcomes. Radiological union occurred at a mean of 11.03 ± 1.97 weeks, while return to full weight-bearing and work occurred within the observed postoperative period. Wound-related complications were limited to 10% of patients, with no deep infection or reoperation reported.

Importantly, the absence of a significant correlation between postoperative Böhler's angle and AOFAS score suggests that restoration of radiographic anatomy alone does not fully determine functional recovery. These findings are broadly comparable with prospective STA evidence reporting satisfactory alignment, union and functional recovery with limited wound morbidity [12].

Radiological outcomes: Restoration of calcaneal architecture is a central objective in the operative management of displaced intra-articular fractures because collapse of the posterior facet and alteration of calcaneal height and width can adversely affect hindfoot biomechanics. In the present cohort, Böhler's angle increased from $9.79 \pm 3.27^\circ$ preoperatively to $28.65 \pm 2.26^\circ$ postoperatively, while Gissane's angle decreased from $127.00 \pm 4.19^\circ$ to $121.20 \pm 1.61^\circ$, with both changes statistically significant ($p < 0.001$). Calcaneal height increased from 35.08 ± 1.09 to 41.57 ± 1.44 mm, whereas width decreased from 47.59 ± 1.46 to 36.83 ± 1.47 mm, indicating restoration of overall calcaneal morphology. These findings are consistent with comparative literature indicating that STA can provide satisfactory restoration of calcaneal anatomy while avoiding the

extensive soft-tissue exposure associated with the extensile lateral approach. Meta-analyses have reported broadly comparable postoperative Böhler's angle, Gissane's angle and calcaneal dimensions between STA and extensile lateral approaches, supporting the ability of limited exposure techniques to achieve adequate radiological reduction [6,7,9]. Prospective CT-based evidence has similarly demonstrated maintenance of posterior facet reduction and satisfactory postoperative Böhler's angle following STA fixation [11,12]. The present findings therefore reinforce the concept that limited exposure does not necessarily preclude restoration of key calcaneal parameters when fracture reduction is appropriately performed. Evidence comparing screw and plate constructs through STA also indicates that both fixation strategies can provide satisfactory functional and radiological outcomes, although fixation choice may influence maintenance of reduction [13].

Functional recovery: Radiological restoration was accompanied by clinically favourable functional recovery. The mean postoperative AOFAS score was 81.27 ± 14.89 , with 24 of 30 patients (80%) classified as having good or excellent outcomes. Subtalar movement was unrestricted in one-third of patients and mildly restricted in a further 46.7%, while the majority achieved full weight-bearing within approximately 9–10 weeks. The mean time to return to work was 3.54 ± 1.21 months. These findings indicate that recovery following STA fixation extends beyond fracture union to progressive restoration of hindfoot mobility and functional loading.

The functional results are broadly consistent with previous STA series and comparative studies reporting satisfactory functional outcomes following minimally invasive fixation. [6] Reported no significant difference in functional outcome between STA and extensile lateral approaches, while [7] similarly found comparable clinical outcomes between the two approaches.

A prospective CT-based study by [12] also reported improvement in functional outcomes following STA fixation and found no significant correlation between postoperative Böhler angle and patient-reported functional scores, which is consistent with the present finding. Importantly, the present study found no significant correlation between postoperative Böhler's angle and AOFAS score ($r = -0.065$, $p = 0.734$). This suggests that restoration of a radiographic parameter should not be interpreted as a surrogate for overall functional recovery. Pain, subtalar mobility, soft-tissue recovery, fracture complexity, rehabilitation and patient-specific factors may all contribute to the final functional result. This finding should

nevertheless be interpreted cautiously because of the small sample size and single-centre design.

Soft-tissue complications: Soft-tissue preservation is one of the principal rationales for minimally invasive approaches to calcaneal fractures. In the present series, only three patients (10%) developed wound-related complications: two superficial infections and one wound dehiscence. No deep infection or reoperation was reported. This relatively limited complication profile is clinically relevant given the vulnerability of the lateral hindfoot soft tissues and the recognised wound morbidity associated with extensive lateral exposure.

The observed findings are consistent with the broader literature. A randomised clinical trial by [5] reported fewer wound complications with STA than with the extended lateral approach, while [7] similarly identified lower wound-complication rates with the minimally invasive approach. [6] Subsequently demonstrated a significantly lower risk of wound-healing complications with STA across comparative studies, although the authors found broadly similar functional and radiological outcomes between approaches. More recently, [8] reported a higher risk of postoperative wound-related complications with the extensile lateral approach in an updated meta-analysis, whereas [14] demonstrated that wound-complication rates following STA vary across geographical settings. Long-term comparative evidence has also reported similar wound, clinical and radiological outcomes between STA and ELA when the same locking plate construct was used [10]. The present 10% rate should therefore be interpreted within the context of the small sample and single-centre setting rather than as evidence of a definitive complication rate.

Sanders classification and clinical implications: Fracture severity did not demonstrate a statistically significant association with functional outcome in this cohort. Mean AOFAS scores were 83.92 ± 15.91 for Sanders II, 76.60 ± 14.64 for Sanders III and 83.13 ± 14.07 for Sanders IV fractures (ANOVA $p=0.491$). Similarly, wound complications were not significantly associated with Sanders classification ($p=0.476$).

These subgroup findings should be interpreted cautiously because each Sanders category contained relatively few patients, particularly type IV fractures. The reliability of Sanders classification has also been shown to be moderate between observers, particularly when fracture subclasses are considered [15]. Nevertheless, the results suggest that fracture classification alone may not capture the full spectrum of determinants of recovery following STA fixation. This is consistent with the broader literature, in which clinical outcomes following calcaneal fracture

fixation are influenced by multiple factors including fracture morphology, quality of reduction, soft-tissue status and rehabilitation rather than by classification alone [6,9]. Overall, the findings support STA as a technically viable approach for appropriately selected displaced intra-articular calcaneal fractures, while recognising that outcomes remain multifactorial.

Limitations

This study has several limitations. The relatively small sample size and single-centre design may limit the generalisability of the findings. The non-randomized, single-arm design and absence of a control group preclude direct comparison of the sinus tarsi approach with the extensile lateral approach and do not permit conclusions regarding comparative superiority. Subgroup analyses by Sanders classification were also limited by the small number of patients within each fracture category. Finally, the follow-up period may be insufficient to determine longer-term outcomes such as post-traumatic subtalar arthritis and sustained functional benefit.

Conclusion

In this prospective cohort, minimally invasive sinus tarsi fixation of closed, displaced intra-articular calcaneal fractures was associated with satisfactory restoration of calcaneal morphology and generally favourable functional recovery. Most patients achieved good or excellent AOFAS outcomes, with radiological union occurring within the observed follow-up period and a limited frequency of wound complications. These findings support the feasibility and clinical utility of the sinus tarsi approach in appropriately selected fractures. However, larger multicentre comparative studies with longer follow-up are required to establish its comparative effectiveness and long-term outcomes.

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