

Outcomes of tibiototalcalcaneal (TTC) nailing in ankle fractures in diabetic patients with Charcot neuropathy

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ABSTRACT

This study aimed to evaluate the clinical and radiographic outcomes of tibiototalcalcaneal (TTC) nailing in diabetic patients with Charcot neuropathy and ankle fractures. A total of 84 patients underwent TTC nailing between December 2022 and June 2024. Functional outcomes were assessed using the Foot and Ankle Outcome Score (FAOS). Significant improvement was observed, increasing from a preoperative mean of 19.9 ± 3.81 to 72.6 ± 11.66 at six months post-operatively ($p < 0.001$). Union was achieved in 75 % of patients, with delayed union in 17.9 % and nonunion in 7.1 %. Postoperative complications included superficial infections (7.1 %) and deep infections (3.6 %). No significant correlations were found between final FAOS scores and patient demographics or diabetes-related factors. TTC nailing is a reliable treatment option for this high-risk population.

Clinical trial number: not applicable.

Introduction

Diabetic patients constitute approximately 12.5 % of patients with diabetes undergo surgical intervention for rotational ankle fractures [1,2]. These patients are at a significantly higher risk of postoperative complications, with reported rates ranging from 26 % to 47 %, compared to 15 % in non-diabetic individuals [3–5]. Diabetes mellitus (DM) is associated with an increased likelihood of amputation, higher rates of secondary surgeries, and poorer functional outcomes following ankle fracture fixation [6]. Due to these risks, non-surgical management has historically been considered a safer option for diabetic patients with acute ankle fractures [7].

Ankle arthrodesis is commonly used as a salvage procedure for conditions, such as Charcot arthropathy and failed fracture fixation. Techniques include tibiototalcalcaneal (TTC) hindfoot nailing, circular external fixation, and tibiotalar arthrodesis using crossed screws or plating. Although primary arthrodesis is effective for managing severe pilon fractures, its role in acute diabetic ankle fractures without Charcot arthropathy remains unclear [8].

The TTC nailing technique offers several advantages including smaller incisions, reduced soft tissue disruption, and preservation of the biological healing environment. These benefits make it particularly suitable for diabetic patients, who often present with poor bone quality, compromised soft tissue integrity, and challenges in adhering to nonweight-bearing protocols [9].

The primary objective of this study was to evaluate the complication rates and functional outcomes of TTC nailing in patients with diabetes, ankle fractures, or Charcot arthropathy. The secondary objective was to assess the mean time to weight bearing and union

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rates.

Patients and methods

This prospective clinical study enrolled 84 patients with diabetes who presented with unstable displaced ankle fractures and impaired deep sensation, all of whom underwent TTC nailing. This study was conducted between December 2022 and June 2024.

Follow-up period

The **mean follow-up duration** for all patients was **6 months**, with a range of **5 to 7 months**. Postoperative evaluations were conducted at regular intervals, including **6 weeks, 3 months, and 6 months**, to monitor patient progress and outcomes.

Inclusion criteria

Patients of both sexes and all occupations aged 40–70 years were included in this study. This study specifically targeted patients with diabetes diagnosed with Charcot neuropathy, who presented with either recent or neglected ankle fractures. Only cases with an ankle-brachial index (ABI) ranging from 0.65 to 1.2 were eligible for enrollment. Additionally, the participants were required to be active and capable of community ambulation.

Exclusion criteria

Patients with active infection at the time of presentation were excluded from the study. Patients with open ankle fractures or fractures with previously failed instrumentation were also excluded. These exclusions were implemented to ensure a homogeneous study population and minimize confounding variables that could affect the outcomes of TTC nailing.

Operative technique

Type of nail used

In this study, two types of intramedullary nails were employed for the management of ankle fractures in diabetic patients with Charcot neuropathy, selected based on fracture pattern and patient-specific anatomical considerations:

1. Supracondylar femoral nail:
 - This nail type was utilized in **24 patients (28.6 %)**, particularly for fractures requiring extended stabilization or in cases with significant bone collapse or deformity.
 - The nail dimensions ranged from **25 cm to 30 cm in length** and **8–12 mm in diameter**, ensuring optimal stability while minimizing the risk of postoperative complications.
2. Straight tibio-calcaneal nail:
 - A straight tibio-calcaneal nail was used in **60 patients (71.4 %)**, as it is specifically designed for ankle arthrodesis and offers biomechanical advantages, including reduced soft tissue disruption and improved weight-bearing capacity.

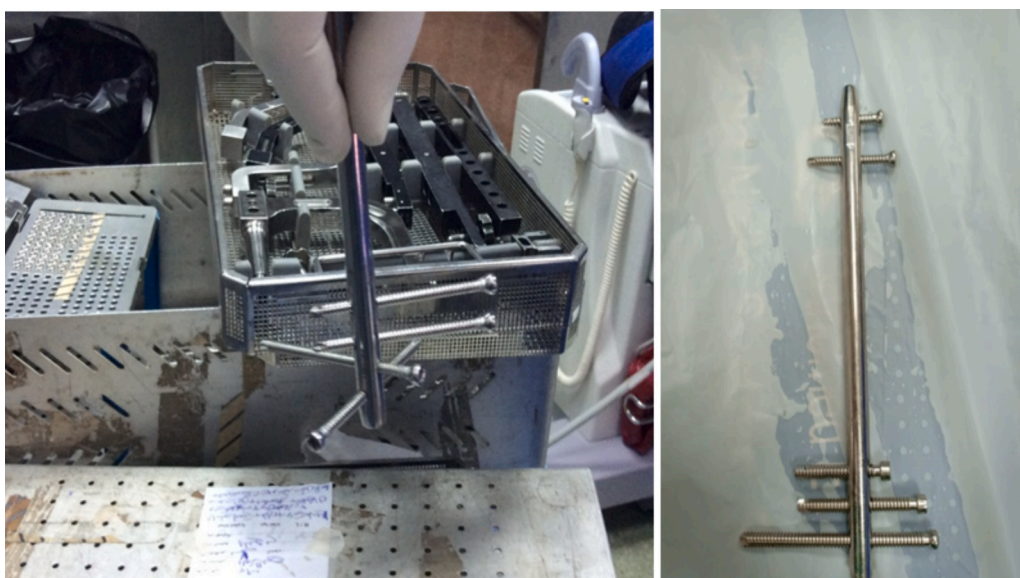


Fig. 1. Intraoperative photograph showing the nail used for fusion ankle fusion nail (right) and supracondylar femoral nail (left).

- The nail dimensions ranged from **20 cm to 25 cm in length** and **8–12 mm in diameter**, providing sufficient rigidity and stability for the majority of cases)Fig. 1).

Both nail types were meticulously inserted under **fluoroscopic guidance** to ensure precise alignment and secure fixation. No instances of nail breakage or malalignment were observed during the follow-up period.

Following the administration of prophylactic antibiotics, patients were positioned in the supine position on the operating table. All procedures were performed under fluoroscopic guidance using a Siemens C-arm. Initial closed reduction and temporary stabilization were achieved using crossed 2.0 mm Kirschner wires. A guidewire (Synthes, West Chester, PA, USA) was advanced to the center of the superior surface of the talus, and the tibial canal was reamed using a flexible reamer system, progressing from 8 mm to 12 mm in 2 mm increments. The TTC retrograde nail (Synthes, West Chester, PA, USA) was then inserted over the guidewire. Fracture reduction and nail placement were confirmed using fluoroscopy, ensuring neutral dorsiflexion, 7 degrees of external rotation, and 2 degrees of hindfoot valgus. Distal and proximal locking were achieved using four 5.0 mm locking screws. Finally, the incision was closed in layers using absorbable sutures.

Statistical analysis of study data

Data were analyzed using IBM SPSS (version 23). Quantitative data were summarized using means, standard deviations, and ranges. Categorical variables were presented as counts and percentages. Statistical significance was defined as $p < 0.05$.

Results

This study included 84 diabetic patients with ankle fractures and peripheral neuropathy affecting sensation, who were treated with TTC nailing.

Preoperative data

Among all the studied patients, 48 (57.14 %) reported preoperative pain. The mean preoperative FAOS score was 19.9 ± 3.81 , ranging from 14 to 27 (Table 1).

Postoperative complications

Postoperative complications included wound infections, categorized as superficial or deep. Superficial infections occurred in six patients (7.1 %), characterized by localized erythema and mild discharge around the surgical site. Deep infections, on the other hand, were observed in three patients (3.6 %), affecting deeper tissues and requiring more aggressive management, including hardware removal, after achieving complete bone consolidation. Furthermore, six patients (7.1 %) developed advanced pathological deformities characterized by structural abnormalities, such as collapse of the pedal arch due to repeated microtrauma and instability secondary to underlying Charcot arthropathy. These complications underscore the importance of vigilant monitoring and proactive TTC management after nailing.

Union rates

The union outcomes after TTC nailing in diabetic patients with Charcot neuropathy and ankle fractures have demonstrated favorable results. The average time to union was 11.1 ± 1.88 weeks, ranging from 8 to 15 weeks. Successful bone union was achieved in 63 patients (75 %), whereas delayed bone union was achieved in 15 patients (17.9 %). Non-union was observed in six patients (7.1 %) (Table 2).

Correlation analysis

No statistically significant correlation was found between the final FAOS score and factors such as age, body mass index (BMI), duration of DM, or HbA1c levels (Table 4).

Table 1
Preoperative data in all studied patients ($n = 84$).

Preoperative pain	Yes: 48 (57.14 %) No: 36 (42.86 %)
Preoperative FAOS	Mean \pm SD: 19.9 ± 3.81 Range: 14–27

Note: FAOS = Foot and Ankle Outcome Score.

Table 2
Time to union in all studied patients (n = 84).

Time to union (weeks)	Mean ± SD: 11.1 ± 1.88 Range: 8–15
Union type	Normal union: 63 (75 %) Delayed union: 15 (17.9 %) Non-union: 6 (7.1 %)

The average time to union was 11.1 ± 1.88 weeks, with a range of 8–15 weeks.

FAOS score improvement

The score showed a significant improvement, increasing from a preoperative average of 19.9 ± 3.81 to 53.7 ± 12.11 at 6 weeks postoperatively ($p < 0.001$). Further improvement was observed at 3 months after surgery, with the mean score reaching 71.7 ± 12.9, and at 6 months postoperatively, the average score was 72.6 ± 11.66 ($p < 0.001$) (Table 3).

Final results

According to the FAOS classification at six months postoperatively, the outcomes demonstrated significant improvement in functional recovery among the studied patients. Specifically, 54 patients (64.3 %) achieved excellent results, 24 patients (28.6 %) showed good outcomes, and 6 patients (7.1 %) were classified as poor. These findings highlight the efficacy of TTC nailing in the treatment of ankle fractures in diabetic patients with Charcot neuropathy.

Case example

- A 50-year-old female was diagnosed with left Charcot ankle fracture. She had uncontrolled type 2 diabetes, which increased the complexity of her condition and increased the risk of complications. She had sustained a bimalleolar fracture one week prior to presentation. The patient underwent TTC nailing as part of the study and her postoperative course was closely monitored. Six months postoperatively, her FAOS score improved significantly from a preoperative baseline of 28 (28 %) to 68 (79 %), reflecting substantial functional recovery. This case highlights the effectiveness of TTC nailing in achieving favorable outcomes even in high-risk diabetic patients with Charcot neuropathy and ankle fractures.
- Figures:
- Fig. (2), Fig. (3), Fig. (4), Fig. (5), Fig. (6), Fig. (7), Fig. (8)

Operative technique

Open retrograde TTC ankle nailing with ankle fusion.

Complications

None reported.

Table 3
FAOS Score improvement in all studied patients (n = 84).

	Mean ± SD	Range	T-value	P-value
Preoperative	19.9 ± 3.81	14–27	–	–
6 weeks postoperative	53.7 ± 12.11	27–68	13.87	<0.001
3 months postoperative	71.7 ± 12.9	30–84	19.95	<0.001
6 months postoperative	72.6 ± 11.66	32–82	22.35	<0.001

Significant improvement was observed in the FAOS score at 6 weeks postoperatively, increasing from 19.9 ± 3.81 to 53.7 ± 12.11 ($p < 0.001$).
Explanation of Values below the Table:

1. Mean ± SD:
Represents the **mean (average)** value along with the **standard deviation (SD)**, which indicates the variability or dispersion of the data points around the mean for each time period.
2. Range:
Refers to the **minimum (lower)** and **maximum (upper)** values observed in the dataset, providing an overview of the spread of scores.
3. T-value:
Represents the **t-test statistic**, which is used to determine the significance of the difference between two groups or time periods. A higher absolute t-value indicates a greater difference between the groups.
4. P-value:
Indicates the **level of statistical significance**. A p-value <0.05 (typically) suggests that the observed differences are statistically significant and not due to random chance.

Table 4Correlation between final FAOS Score and patient parameters ($n = 84$).

Parameter	Correlation coefficient (r)	P-value
Age	0.0114	0.94
Body mass index	0.0022	0.99
Duration of Diabetes Mellitus	0.01	0.96
HbA1c	0.2001	0.31

No significant correlations were found between the final FAOS score and age, BMI, diabetes duration, or HbA1c levels.

**Fig. 2.** Preoperative clinical picture of the left ankle of the patient

This figure shows the preoperative clinical condition of the left ankle in a representative patient. It highlights the deformity and swelling associated with the Charcot ankle fracture before surgical intervention.

**Fig. 3.** Pre-operative radiograph

These radiographic images depict the preoperative state of the ankle fracture in both anteroposterior (AP) and lateral views. The AP view demonstrates the alignment of the ankle joint, while the lateral view provides insight into the extent of the fracture and any associated collapse and displacement.

Six-month postoperative score

The FAOS score improved significantly from 28 preoperatively (28 %) to 68 postoperatively (79.1 %), representing 79 % improvement.

Discussion

Charcot neuroarthropathy of the foot and ankle leads to severe deformities due to loss of neurological function and secondary



Fig. 4. Postoperative AP and lateral radiograph after open TTC nailing

This figure displays the immediate postoperative radiographic results following tibiototalcaneal nailing. The AP and lateral views confirm proper alignment and fixation of the fracture, ensuring stability and preparing the site for healing.



Fig. 5. Six weeks postoperative lateral, AP, and axial radiographs

These radiographs taken six weeks after surgery show early signs of bone healing. The lateral, AP, and axial views collectively demonstrate the callus formation at the fracture site, indicating union initiation.

vascular complications. This condition results in pathological fractures and pedal arch collapse caused by repeated microtraumas. The resulting deformities often lead to ulceration due to pressure on bony prominences, and the associated instability makes conservative treatments, such as bracing, challenging and frequently results in wound complications [10].

Many authors suggest that Charcot arthropathy often develops from repeated minor trauma or isolated major trauma to neuropathic joints. In patients with diabetes, the condition may be triggered by joint trauma and exacerbated by a lack of protective sensations, which predisposes them to the disease [11].

In the present study, the average time to union was 11.1 ± 1.88 weeks (ranging 8–15 weeks). Union was achieved in 63 (75 %) patients, 15 (17.9 %) had delayed union, and six (7.1 %) experienced nonunion. These findings are consistent with those of the study by Abdelmoneim et al. (2020) [12], in which 60 % of patients achieved complete union, 30 % achieved non-union, and 10 % had stable fibrous union. The mean time to union was 6.79 months (range, 3–8 months).

In the present study, the FAOS score improved significantly from a preoperative mean of 19.9 ± 3.81 to 53.7 ± 12.11 at 6 weeks postoperatively ($p < 0.001$). Further improvement was observed at 3 months postoperatively, with a mean score of 71.7 ± 12.9 , and at 6 months postoperatively, with a mean score of 72.6 ± 11.66 ($p < 0.001$). These results align with the findings of Vitiello et al. (2020) [13], who reported a mean overall improvement in the FAOS score of 72.5 % (preoperatively, 40 points vs. postoperatively, 69 points; $p < 0.001$).

The final results, according to the FAOS classification, at six months postoperatively demonstrated favorable functional outcomes among the studied patients. Specifically, 54 patients (64.3 %) achieved excellent results, 24 patients (28.6 %) showed good outcomes, and 6 patients (7.1 %) were classified as poor. These findings underscore the effectiveness of TTC nailing in improving ankle function and achieving positive clinical outcomes in patients with diabetes, Charcot neuropathy, or ankle fractures. Additionally, no statistically

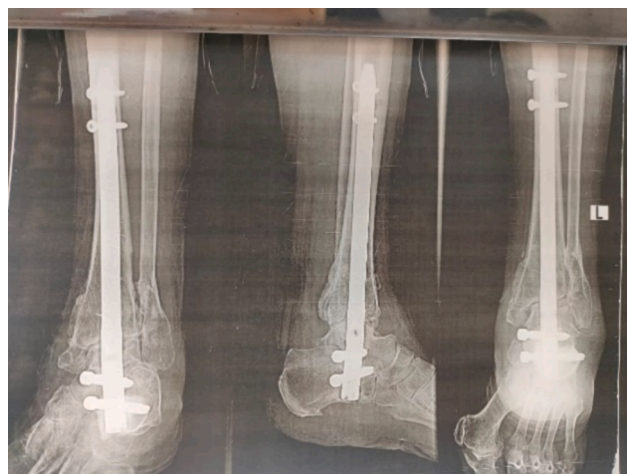


Fig. 6. Three months postoperative lateral, AP, and axial radiograph

These images reveal significant progress in bone union and stabilization at three months postoperatively. The lateral, AP, and axial views confirm the ankle joint's proper alignment and healing.

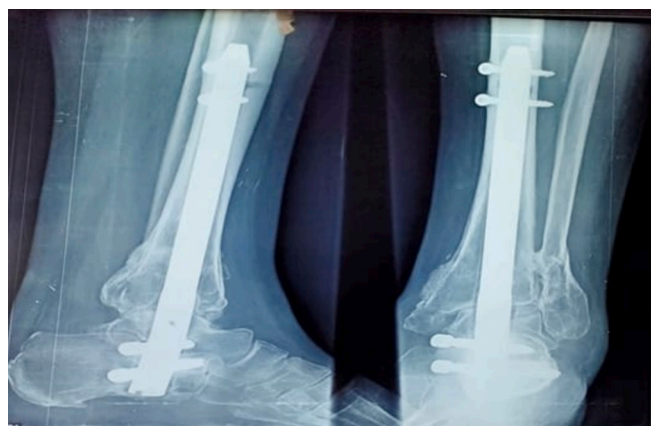


Fig. 7. Six months postoperative lateral, AP, s

This figure presents the radiographic evidence of successful bone fusion six months after tibiototalcalcaneal nailing. The lateral, AP, and axial views confirm complete union and restoration of anatomical alignment, highlighting the procedure's effectiveness.

significant correlation was found between the final FAOS score and factors, such as age, BMI, duration of DM, or HbA1c levels (Table 4).

TTC arthrodesis performed with intramedullary nail fixation has demonstrated favorable outcomes in terms of the union rate, functional improvement, and reduced complications. TTC arthrodesis has demonstrated favorable clinical outcomes both in the short- and long-term in general medical practice. However, investigations into the outcomes of patients with diabetes are limited, with most studies focusing solely on Charcot arthropathy [14].

Retrograde intramedullary ankle-nail fixation has gained popularity because of its clear mechanical advantages. This procedure provides stable fixation, eliminating the need for additional external immobilization devices such as casts or braces. Bone union rates range 88–100 % among non-diabetic patients treated without external immobilization [15].

A similar pattern has been observed in patients with Charcot arthropathy, where external immobilization is often unnecessary because of the strength of the internal fixation. In our study, all 84 patients diagnosed with Charcot arthropathy achieved excellent functional recovery and were able to bear full weight on their affected limb. Consolidation was observed in all cases, with bone union in 63 (75 %) cases and solid fibrous union in six (7.1 %) cases. The remaining patients (15 patients (17.9 %) experienced delayed union, and their fractures took longer to heal than those who achieved complete bone or solid fibrous union. No additional nonunions were reported in the six cases mentioned above [16].

Currently, diabetic patients undergoing TTC arthrodesis experience a significant incidence of postoperative complications regardless of the type of internal fixation used. Studies with the largest cohorts of patients with diabetes have primarily focused on those with Charcot arthropathy because nail fixation is more commonly used in this population. Retrograde intramedullary nail



Fig. 8. Six months postoperative clinical pictures

These clinical photographs illustrate the final outcome at six months postoperatively. They show reduced swelling, improved alignment, and the absence of wound complications, demonstrating the functional recovery achieved through tibiototalcaneal nailing.

fixation is recommended for ankle arthrodesis in patients with Charcot arthropathy irrespective of hindfoot involvement [17].

Due to the limited number of cases, the statistical significance of our findings is low [18] however, a noticeable trend toward mid-to long-term infections was observed, with superficial infections affecting six patients (7.1 %) and deep infections requiring hardware removal observed in three patients (3.6 %). The total number of infection cases was 9 (10.7 %). Furthermore, superficial infections were managed conservatively with oral antibiotics and local wound care, whereas deep infections involved deeper tissues and necessitated more aggressive interventions, including intravenous antibiotics and hardware removal, once complete bone consolidation was achieved.

This trend may be attributed to the well-documented susceptibility of diabetic patients to infections combined with the bulky nature of the internal fixation device [12].

Study limitations

This study has several limitations, including its retrospective nature, relatively small patient population ($n = 84$), lack of advanced imaging to confirm osseous union, and relatively short follow-up period.

Conclusion

Our findings indicate that tibiototalcaneal arthrodesis using retrograde intramedullary nails is a successful intervention for treating ankle and hindfoot disorders in patients with diabetes and yields favorable clinical outcomes. Significant improvements in functional recovery and pain alleviation were observed, resulting in high levels of patient satisfaction. TTC nailing in ankle fractures among diabetic patients with Charcot neuropathy is a reliable treatment option and effective method for ankle fusion.

As with all surgical procedures, this intervention is associated with complications that may lead to below-knee amputation in severe cases. Postoperative deep infection was observed in 3 patients (3.6 %). This is a serious complication that can occur even after a significant period. Hardware removal may be considered once complete bone consolidation has been achieved.

Patients consent to the publication of images and data

Prior to participation, all patients voluntarily provided written informed consent for publication of their images and data.

Clinical trial number

Not applicable.

Declaration of Helsinki

This study was conducted in accordance with the principles of the Declaration of Helsinki.

CRediT authorship contribution statement

Sayed Mohamed Elgoyoushi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ahmed Nabawy Morrah:** Data curation, Conceptualization. **Ahmed Mahmoud Kholeif:** Resources, Project administration, Methodology, Conceptualization. **Ahmad Amr Elbadry:** Writing – review & editing, Writing – original draft, Visualization, Funding acquisition, Formal analysis, Conceptualization.

Ethical approval

Ethical approval was obtained from the Institutional Review Board (IRB) of [Research Ethical Committee of Cairo University Faculty of Medicine] (Approval No. [MD-31-2023]) Dated 2023-1-15. Written informed consent was obtained from all participants.

Declaration of Generative AI and AI-assisted technologies in the writing process

We confirmed that artificial intelligence tools, including data collection, analysis, and manuscript preparation, were not utilized in any part of the research process.

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Declaration of competing interest

I hereby declare that I have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. To the best of my knowledge, there are no conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

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Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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