Effectiveness of tibio-talo-calcaneal arthrodesis for Charcot ankle arthropathy: unraveling the impact of glycated hemoglobin on postoperative recovery and complications

Ahmed A. Toreih, Ahmed Abdelbadie, Moawed F. El-Adawy

Department of Orthopedics and Traumatology, Faculty of Medicine, Suez Canal University, Suez Canal, Egypt

Correspondence to Ahmed A. Toreih, MD, Msc, Department of Orthopedics and Traumatology, Faculty of Medicine, Suez Canal University, Suez Canal 41511, Egypt
Tel: +20 101 176 1134;
e-mail: toreih@hotmail.com, ahmed.toraih@med.suez.edu.eg.

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Background
Charcot arthropathy of the ankle is a severe complication of diabetes that can lead to deformity, ulcers, and amputation. Tibio-talo-calcaneal arthrodesis is a surgical technique to stabilize the ankle, but optimal management remains unclear.
Objective
This study aimed to evaluate the functional and radiological effectiveness of tibio-talo-calcaneal arthrodesis using retrograde intramedullary nailing without bone graft for Charcot ankle and achieve stable aligned ankle construct.
Patients and methods
In this prospective study, 31 diabetic patients Eichenholtz stages 2–3 (coalescence or reconstruction phases) Charcot ankle underwent tibio-talo-calcaneal arthrodesis with retrograde nail. The American Orthopedic Foot & Ankle Society ankle-hindfoot score measured outcomes at baseline, 6 months, and 12 months postoperatively. Complications were recorded. Regression analysis identified outcome predictors.
Results
American Orthopedic Foot & Ankle Society scores improved significantly from 17.4±2.37 preoperatively to 73.4±10.5 at 6 months and 81.9±11.5 at 12 months (*P*<0.001). Twelve (38.7%) patients experienced complications including deep vein thrombosis and sepsis. Elevated glycated hemoglobin predicted complications (odds ratio=3.25, *P*=0.010) and longer recovery (*B*=1.353, *P*=0.008). An glycated hemoglobin cutoff of 8.0% predicted complications with 75.0% sensitivity and 78.9% specificity (area under the curve=0.816).
Conclusion
Tibio-talo-calcaneal arthrodesis effectively improved ankle function in Charcot arthropathy but complications were common, emphasizing the importance of perioperative glycemic control.

Keywords:
ankle arthropathy, American Orthopedic Foot & Ankle Society score, Charcot ankle, deep venous thrombus, nonunion, sepsis, tibio-talo-calcaneal arthrodesis

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Introduction

Charcot ankle, also known as Charcot arthropathy, is a debilitating complication of diabetes mellitus (DM) that can lead to the destruction of bones and joints in the neuropathic foot. This chronic condition leads to significant deformities and increases the risk of foot ulcers, often necessitating amputation [1,2]. Peripheral neuropathy is a key factor in the development of Charcot ankle, causing the loss of protective sensation in the feet and leading to repetitive microtrauma and subsequent bone and joint destruction [3]. The clinical presentation of Charcot joint is characterized by painless swelling and extensive damage in the bones and joints, predominantly in ankles. Radiographic findings play a crucial role in confirming the diagnosis [4]. Effective management of Charcot ankle is crucial to prevent gross foot deformities, pressure ulcers, infections, and the need for amputation [5–7]. The current management landscape lacks a consensus or definitive guideline for the optimal strategy of ankle Charcot neuropathy and the appropriate stage at which surgical intervention should be pursued. Nevertheless, it is widely acknowledged that off-loading orthoses, such as total contact casts, braces, or Charcot restraint orthotic walker, are commonly used as initial treatment modalities [8].

Despite the advancement in understanding this condition, the role and timing of surgical intervention remain ambiguous, and the outcomes of such procedures can be unpredictable. Among the surgical options available for addressing Charcot ankle, tibio-

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talo-calcaneal arthrodesis stands out as a notable approach aimed at achieving a pain-free, brace-free, and functionally stable foot [9]. This method has proven effective in managing severe pain and deformities involving the hind part of the ankle, offering a viable alternative for cases of recalcitrant diabetic neuropathic arthropathy. Notably, attaining stable fixation is of utmost importance, especially in cases where the bone exhibits reduced density (osteopenia) [5]. The use of a retrograde locking intramedullary nail is a promising option for Charcot ankle without bone graft, providing good stability and enabling early weight bearing [10]. The procedure involves inserting the nail through the calcaneus and up into the tibia, with the locking screws placed in a retrograde fashion, providing good stability, and enabling early weight bearing [9]. Blade-plate-and-screw fixation is another option for tibio-talo-calcaneal arthrodesis, involving the use of a 95° blade plate and screws for supplemental fixation when needed [11,12]. The use of a lateral compression plate is also an effective alternative to blade plate or intramedullary nail fixation [13]. These surgical techniques offer promising outcomes in achieving a stable, painless, and ulcer-free ankle.

In this study, we primarily aim to evaluate the effectiveness of tibio-talo-calcaneal arthrodesis using a retrograde locking intramedullary nail for the treatment of Charcot ankle without bone graft. In addition, the study sought to investigate the impact of diabetic control and BMI on postoperative complications and the duration of weight bearing without orthosis. By providing insights into treatment outcomes, this research aims to contribute to the understanding and management of Charcot ankle arthropathy, ultimately leading to improved long-term foot function and enhanced patient quality of life.

Patients and methods

Study population

This prospective, single-center study focused on patients with Charcot ankle arthropathy presenting to Suez Canal University hospitals undergoing tibio-talo-calcaneal arthrodesis with retrograde locking intramedullary nail to assess treatment effectiveness. The primary objective was to evaluate the functional and radiological effectiveness of tibio-talo-calcaneal arthrodesis using retrograde intramedullary nailing without bone graft for Charcot ankle and achieve stable aligned ankle construct. Patients aged 18–70 years with Eichenholtz stages 2–3 (coalescence or reconstruction phases) were enrolled. Inclusion criteria were unstable deformity or difficulty walking even in stable deformity, either recent or old onset, and willingness to participate. Exclusion criteria included active ulceration, open infected wounds, prior foot surgery, and noncompliance with follow-up. Patients with both stable and unstable ankle deformities, with or without impending ulceration, were included. The study protocol was approved by the institutional review board (IRB) of the participating institution (5286#), and informed consent obtained. Principles of the Declaration of Helsinki and Good Clinical Practice guidelines were followed to ensure privacy and confidentiality.

Clinical and radiological assessment

Data were collected at baseline, comprising patient demographics, medical history, radiographic imaging, and the American Orthopedic Foot & Ankle Society (AOFAS) ankle-hindfoot score. The AOFAS ankle-hindfoot score is a widely accepted tool used to measure the functional outcomes of foot and ankle surgery. It incorporates questions about pain, function, and alignment, generating a score ranging from 0 (worst) to 100 (best). This score was utilized to compare the functional outcomes of the study participants with those reported in the existing literature. The patients were followed up for 12 months to evaluate treatment outcomes. The follow-up process involved regular assessments of pain, functional status, alignment, and radiographic findings. Radiologically, union was considered when well established passing bone was seen across both edges in at least three different cortices in anteroposterior and lateral views.

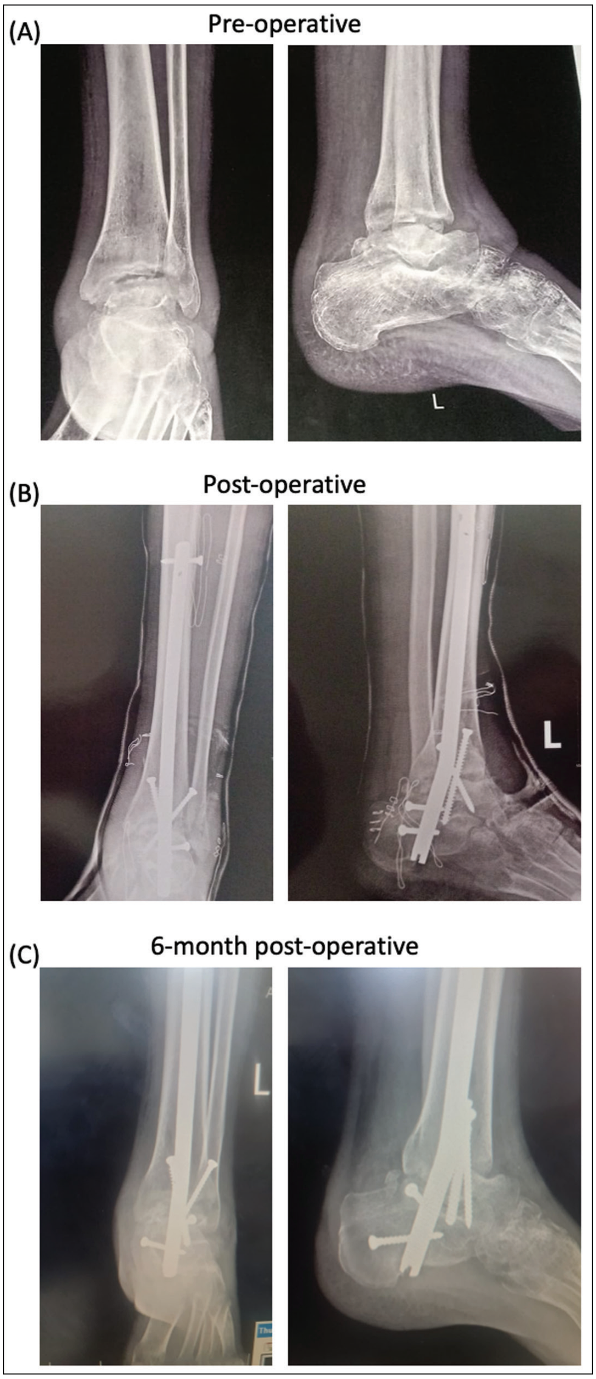
Surgical procedure

The patient was first positioned on the operating table and provided with either general or spinal anesthesia or a regional nerve block to minimize pain and discomfort during the procedure. A small anterolateral incision anterior to peroneos brevis tendon was made for joint access. Soft tissues were carefully dissected, protecting neurovascular structures (saphenous nerve) and tendons. For joint preparation, we removed the remaining cartilage from the ankle joint surfaces using a small osteotome and curette spoon and prepared the bone surfaces for fusion. The bone ends were shaped and smoothed to allow for proper alignment and stability. Subtalar joint was rigidly fixed by reaming and nailing aiming for stability, immobilization and subsequently fibrous union. Next, a traditional interlocking tibial nail (Orthomed Egypt or Egyfix manufacture according to the availability in the hospital) was inserted in a retrograde manner through the calcaneus using a pointed awl, guided by fluoroscopy the awl was introduced in the middle of calcaneus, then guide wire was drilled to the center of talus and driven up into the tibia along guide wire and malleable reaming, passing through the ankle joint. The curvature already present in tibial nail was kept posterolateral to be anatomically suitable as the calcaneus is mildly posterolateral to the talus. Using fluoroscopy, the nail was kept flushing on the bottom just anterior to the calcaneal tuberosity, the nail was secured to the bone using locking screws at both ends to provide stable fixation, two distal screws were applied first oblique (posteromedial and posterolateral) one in the calcaneus and one in the talus using the nail guide, then compression at fusion side was done by gentle hammering, followed by application of proximal one or two screws in the tibia with freehand technique from lateral to medial. Finally, we closed the incision with sutures and applied a sterile dressing to the wound. The patient was then placed in a cast or boot for at least 6 weeks to protect the ankle and promote healing (Figs 1 and 2).

Statistical analysis

The statistical analysis was performed using the *finalFit* package in R (version 4.2.2, 2022-10-31, R Foundation for Statistical Computing, Vienna, Austria) [14,15]. Before analysis, the data underwent thorough cleaning and preprocessing to ensure data accuracy and consistency. Descriptive statistics were used to summarize the characteristics of the study population and the surgical outcomes. Inferential statistics were utilized to assess the effectiveness of the surgical technique in treating different cases of Charcot ankle arthropathy. To compare categorical variables, the study used Pearson's χ^2 test or Fisher's exact test, depending on the sample size and distribution of data. Continuous variables, on the other hand, were compared using the Student's *t* test or Mann–Whitney *U* test, depending on data normality and homogeneity. In addition, related-samples Friedman's two-way analysis of variance by ranks test was used to assess the repeated measures of AOFAS score at preoperative baseline, 6 months, and 12 months postoperatively. Furthermore, demographic variables and comorbidities were also analyzed and compared, categorized by the type of DM. Local Fisher discriminant analysis (LFDA) was performed using the R package *lfda* [16] to analyze preoperative and postoperative AOFAS scores. LFDA transforms the data into a lower-dimensional space while preserving the local data structure. Two-sided tests were used, and statistical significance was set at P value less than 0.05. Next, univariate binary logistic regression analysis was utilized to identify potential predictor indicators for postoperative complications. The results were reported as odds ratios (OR) with corresponding 95% confidence intervals (CI). In addition, receiver operating characteristic curve analysis was conducted to determine the cutoff for glycated hemoglobin (HbA1c) levels that are associated with postoperative complications. The area under the curve, sensitivity,

Figure 1



Radiological imaging and clinical recovery in a 34-year-old male following with diabetic Charcot ankle. (a) Anteroposterior and lateral view of the left ankle, showcasing the presurgical state. (b) Immediate postoperative radiographs following tibio-talo-calcaneal arthrodesis illustrating the insertion of a retrograde locking nail. This nail traverses from the heel bone (calcaneus) into the tibia, seamlessly passing through the ankle joint. Locking screws at both extremities of the nail ensure stable fixation and two lag screws tibiotalar were added to augment the fusion. (c) Radiographs taken 6 months postsurgery demonstrating a successful union. The patient, diagnosed with type I diabetes, had a preceding ankle fracture. His presurgical American Orthopedic Foot and Ankle Society score (AOFAS) stood at a low 19 but showed an impressive improvement postsurgery, reaching 80 after 6 months and further advancing to 89 by the end of the first year. Notably, the patient was able to bear weight within a month postsurgery, with and without the assistance of an orthosis. The fusion time was recorded at 3 months.

Figure 2

Radiographic and clinical recovery in a 50-year-old male with type II diabetes. (a) Preoperative imaging reveals the severity of his joint condition. (b) Intraoperative image shows anterolateral approach to debride the joint. (c) Insertion of guide wire using C-arm fluoroscopy. (d) Intraoperative images showing reaming of medulla and insertion of the nail. (e) Postoperative image on fluoroscopy after insertion of locking screws. (f) A 6-month postoperative radiograph demonstrating a successful union. This patient, having a BMI of 27.5 kg/m^2, hypertension, and posttraumatic arthritis. His baseline American Orthopedic Foot and Ankle Society score (AOFAS) was 25. Postsurgery, his score showed a dramatic rise, reaching 75 shortly after and advancing to 86 by the 6-month checkpoint. Remarkably, he started weight bearing just a month postoperative, both with and without orthosis. Complete fusion was achieved by the 6-month mark, and his recovery journey remained devoid of any complications.

and specificity were calculated to assess the predictive accuracy of the identified cutoff value. Finally, time to weight bearing was assessed with and without orthosis and paired values were compared using related samples Wilcoxon signed-rank test. In addition, linear regression analysis was performed to identify predictor factors for the duration of weight bearing without orthosis following tibio-talo-calcaneal arthrodesis. The model included age, HbA1c level, BMI, and type of diabetes, and a stepwise method was used for variable selection. The adjusted R^2 was used to determine the optimal model.

Results

Characteristics of the study population

The study included a total of 31 participants, with 11 (35.5%) having type I DM and 20 (64.5%) diagnosed with type II DM. The average age of the participants was 55.4±8.5 years. The type I DM group had a relatively younger average age of 50.5±8.5 years compared with the type II DM group, with an average age of 58.0±7.3 years (*P*=0.014). There were 15 (48.4%) males and 16 (51.6%) females. The average weight of the participants was 89.0 kg (SD=12.9), and the average height was 167.2 cm (SD=8.8). The mean BMI of the entire cohort was 31.8 kg/m^2 (SD=4.0), with no significant difference between the type I DM group (mean=31.2 kg/m^2, SD=2.5) and the type II DM group (mean=32.2 kg/m^2, SD=4.6).

As depicted in Table 1, comparison between the type I and type II DM groups did not show significant differences in other clinical variables, including hypertension, chronic obstructive pulmonary disease, smoking, history of diabetic foot ulcers, history of ankle

Table 1 Characteristics of the study participants

Characteristics	Levels	Total (N=31)	Type I DM (N=11)	Type II DM (N=20)	P value
Demographics					
Age	Mean (SD)	55.4 (8.5)	50.5 (8.5)	58.0 (7.3)	**0.014**
Sex	Female	16 (51.6)	4 (36.4)	12 (60.0)	0.37
	Male	15 (48.4)	7 (63.6)	8 (40.0)	
Weight	Mean (SD)	89.0 (12.9)	90.1 (10.9)	88.5 (14.2)	0.74
Height	Mean (SD)	167.2 (8.8)	169.9 (8.0)	165.7 (9.0)	0.20
BMI	Mean (SD)	31.8 (4.0)	31.2 (2.5)	32.2 (4.6)	0.49
Comorbidities					
HbA1c levels	Mean (SD)	8.0 (1.4)	8.5 (1.4)	7.7 (1.3)	0.13
History of diabetic ulcer	No	26 (83.9)	9 (81.8)	17 (85.0)	1.00
	Yes	5 (16.1)	2 (18.2)	3 (15.0)	
Hypertension	No	14 (45.2)	6 (54.5)	8 (40.0)	0.68
	Yes	17 (54.8)	5 (45.5)	12 (60.0)	
Chronic obstructive pulmonary disease	No	25 (80.6)	10 (90.9)	15 (75.0)	0.55
	Yes	6 (19.4)	1 (9.1)	5 (25.0)	
Smoking	No	16 (51.6)	5 (45.5)	11 (55.0)	0.89
	Yes	15 (48.4)	6 (54.5)	9 (45.0)	
History of ankle fracture	No	18 (58.1)	5 (45.5)	13 (65.0)	0.50
	Yes	13 (41.9)	6 (54.5)	7 (35.0)	
Posttraumatic arthritis	No	15 (48.4)	3 (27.3)	12 (60.0)	0.17
	Yes	16 (51.6)	8 (72.7)	8 (40.0)	
Avascular necrosis	No	25 (80.6)	7 (63.6)	18 (90.0)	0.19
	Yes	6 (19.4)	4 (36.4)	2 (10.0)	
History of deep venous thrombosis	No	29 (93.5)	10 (90.9)	19 (95.0)	1.00
	Yes	2 (6.5)	1 (9.1)	1 (5.0)	
Peripheral vascular diseases	No	21 (67.7)	5 (45.5)	16 (80.0)	0.12
	Yes	10 (32.3)	6 (54.5)	4 (20.0)	

Data is presented as n (%) or mean (SD).
DM, diabetes mellitus; HbA1c, glycated hemoglobin.
Bold value indicates the mean age of patients with type II DM was higher compared to patients with type I DM. p-value < 0.05.

fracture, posttraumatic arthritis, avascular necrosis, and peripheral vascular diseases. The average HbA1c level was higher in the type I DM group (8.5 ± 1.4) compared with the type II DM group (7.7 ± 1.3), but the difference was not statistically significant (P=0.130).

Postoperative functional improvement

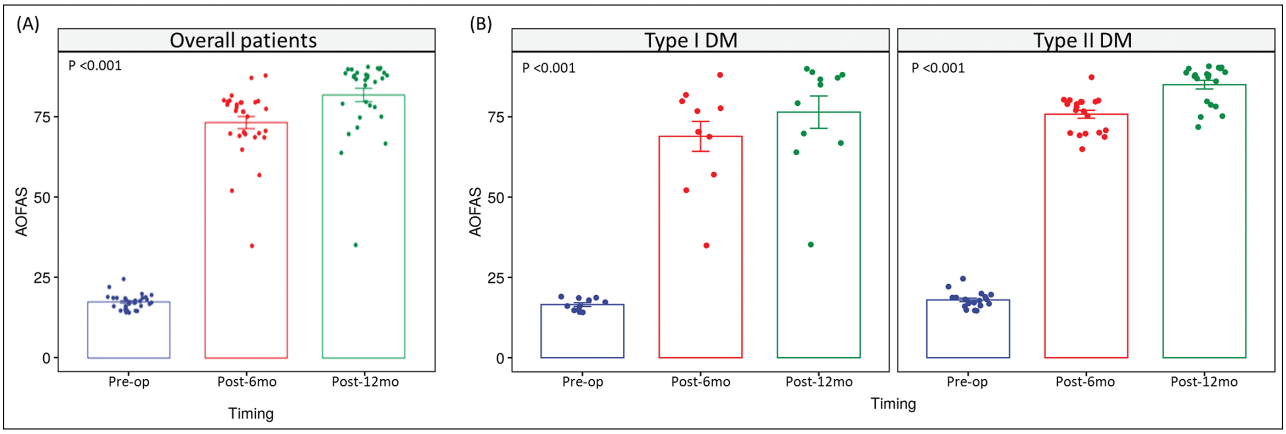
The surgical outcomes of tibio-talo-calcaneal arthrodesis for Charcot ankle without bone graft were assessed using the AOFAS ankle-hindfoot score. The analysis demonstrated a significant improvement in the AOFAS score from pretreatment to 6 months posttreatment, with a mean difference of 55.87 (P<0.001, 95% CI: 52.16–59.58). Similarly, there was a significant increase in the AOFAS score from pretreatment to 12 months posttreatment, with a mean difference of 64.48 (P<0.001, 95% CI: 60.47–68.50) (Fig. 3a). The average preoperative AOFAS score was 17.4 ± 2.37, which improved to 73.4 ± 10.5 at 6 months posttreatment and further increased to 81.9 ± 11.5 at 12 months posttreatment. Pairwise comparison of the three timeline measures (pretreatment, 6 months, and 12 months) revealed statistically significant differences (P<0.001). Stratified analysis by type of diabetes (type I and type II) yielded similar results, confirming the effectiveness of the surgical intervention in both groups (Fig. 3b).

Table 2 provides a summary of the short-term and long-term surgical outcomes at different time points for the total study population and the subgroups based on the type of diabetes. The results show that patients with both type I and type II DM experienced significant improvements in their AOFAS scores following tibio-talo-calcaneal arthrodesis, with the type II DM group generally exhibiting slightly higher scores at 6 months and 12 months posttreatment compared with the type I DM group.

Complication rates of tibio-talo-calcaneal arthrodesis

In the study, out of the total 31 participants who underwent tibiotalocalcaneal arthrodesis for Charcot ankle without bone graft, 12 individuals experienced complications. Among these complications, there were five cases of deep venous thrombus (DVT), and one case of DVT with pulmonary embolism. In addition, five cases of sepsis were also observed. Among the sepsis cases, one was identified as Methicillin-resistant *Staphylococcus aureus* infection, and another showed *S. aureus*. In addition, there was one case of *Pseudomonas*

Figure 3



Postoperative functional improvement following tibio-talo-calcaneal arthrodesis for Charcot ankle without bone graft. (a) Overall. (b) Stratified by type of diabetes. American Orthopedic Foot & Ankle Society ankle-hindfoot score is reported on *Y*-axis. Related-samples Friedman's two-way analysis of variance by ranks test was used. *P* values were less than 0.001.

Table 2 Surgical outcomes following tibio-talo-calcaneal arthrodesis for Charcot ankle without bone graft

Characteristics	Levels	Total (*N*=31)	Type I DM (*N*=11)	Type II DM (*N*=20)	*P* value
Functional assessment					
Preoperative AOFAS	Mean (SD)	17.4 (2.4)	16.5 (2.0)	18.0 (2.5)	0.10
6-month AOFAS	Mean (SD)	73.4 (10.5)	68.9 (15.4)	75.8 (5.6)	0.08
12-month AOFAS	Mean (SD)	81.9 (11.5)	76.5 (16.7)	85.0 (6.0)	**0.046**
Complications					
Deep venous thrombus	No	25 (80.6)	9 (81.8)	16 (80.0)	0.90
	Yes	6 (19.4)	2 (18.2)	4 (20.0)	
Pulmonary embolism	No	30 (96.8)	11 (100.0)	19 (95.0)	0.45
	Yes	1 (3.2)	0	1 (5.0)	
Postoperative sepsis	No	26 (83.9)	9 (81.8)	17 (85.0)	0.82
	Yes	5 (16.1)	2 (18.2)	3 (15.0)	
Need debridement	No	29 (93.5)	10 (90.9)	19 (95.0)	0.64
	Yes	2 (6.5)	1 (9.1)	1 (5.0)	
Follow-up					
Fusion	Union	29 (93.5)	9 (81.8)	20 (100)	0.24
	Nonunion	2 (6.5)	2 (18.2)	0	
Time to fusion	3 months	7 (22.6)	2 (18.2)	5 (25.0)	0.37
	6 months	13 (41.9)	4 (36.4)	9 (45.0)	
	9 months	7 (22.6)	2 (18.2)	5 (25.0)	
	12 months	2 (6.5)	1 (9.1)	1 (5.0)	

Data is presented as *n* (%) or mean (SD).
AOFAS, American Orthopedic Foot & Ankle Society ankle-hindfoot score; DM, diabetes mellitus.
Bold value indicates patients with type II DM had higher AOFAS score at 12 month compared to type I DM, indicating better outcomes *p*-value < 0.05.

aeruginosa infection, they were all treated with antibiotics according to culture and sensitivity until infection subsided, two of them needed debridement and suction drains for days but all of them healed successfully and none of them needed amputation (Table 2).

The logistic regression analysis revealed that a high preoperative HbA1c level was a significant indicator for the development of postoperative complications. Patients with high HbA1c levels were associated with a three-fold increased risk of complications (OR=3.25, 95% CI=1.33–7.95, *P*=0.010). Furthermore, the receiver operating characteristic analysis showed that the HbA1c level had good discriminatory power in predicting postoperative complications, with an area under the curve of 0.816 and standard error of 0.083. The optimal cutoff value for HbA1c levels to predict complications was found to be 8.0, with a sensitivity of 75.0% and specificity of 78.9% (Table 3).

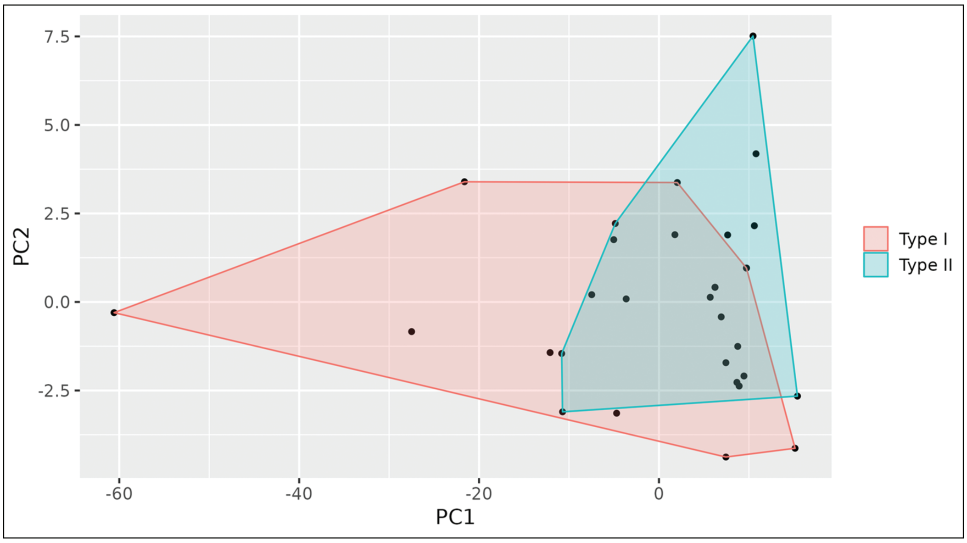
In addition to HbA1c levels, other risk factors were evaluated using univariate binary logistic regression

Table 3 Predictor risk factors for postoperative complications

Risk factor	OR	95% CI	*P* value
Age at surgery	1.01	0.92–1.09	0.86
Sex: male vs. female	1.93	0.45–8.33	0.38
BMI	1.24	.99–1.55	0.06
Smoking	1.11	0.26–4.72	0.88
Hypertension	0.23	0.05–1.08	0.06
Chronic obstructive pulmonary disease	1.78	0.29–10.7	0.53
Peripheral vascular disease	7.46	1.38–40.2	**0.019**
Type of diabetes: types II vs. I	0.65	0.14–2.89	0.57
HbA1c level	3.25	1.33–7.95	**0.010**
History of ankle fracture	0.98	0.23–4.25	0.98
Posttraumatic arthritis	1.56	0.36–6.69	0.55
Avascular necrosis	1.78	0.29–10.7	0.53

Univariate binary logistic regression analysis was used. Odds ratio (OR) and 95% confidence interval (CI) are reported.
HbA1c, glycated hemoglobin.
Bold value indicates risk factors such as peripheral vascular disease increase risk of overall post-operative compilations by 7 folds.

Figure 4



Scatter plot depicting the results of local Fisher discriminant analysis (LFDA) of preoperative and postoperative (6 months and 12 months) AOFAS scores for patients with type I and type II diabetes. The overlapping between the two diabetes groups in the lower-dimensional space suggests similarities in their functional outcomes after tibio-talo-calcaneal arthrodesis. AOFAS, American Orthopedic Foot & Ankle Society.

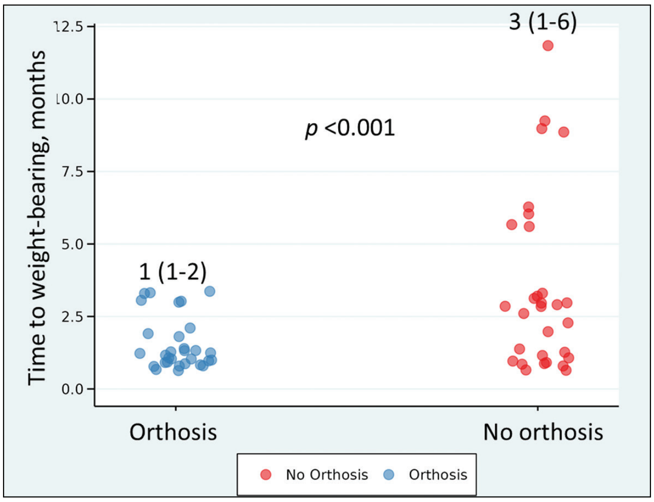
analysis. Among the examined risk factors, peripheral vascular disease showed a significant association with postoperative complications, presenting a substantially higher OR (OR=7.46, 95% CI=1.38–40.2, *P*=0.019). However, other factors such as age at surgery, sex, BMI, smoking, hypertension, type of diabetes, history of ankle fracture, posttraumatic arthritis, and avascular necrosis did not show statistically significant associations with postoperative complications.

Fusion rates following tibio-talo-calcaneal arthrodesis

Out of the total 31 participants, 29 achieved fusion (union) accounting for 93.5% cure rate, whereas two (6.5%) male patients experienced nonunion postoperatively with no significant difference in fusion rates between type I DM and type II DM groups (*P*=0.24) (Table 2). One patient, aged 47, had a BMI of 33.7 kg/m^2, type I diabetes, and posttraumatic arthritis, with an HbA1c level of 8.3. The other patient, aged 62, had a BMI of 28.4 kg/m^2, type I diabetes, a history of smoking and chronic obstructive pulmonary disease, and an HbA1c level of 11. Both patients had peripheral vascular disease, but no history of diabetic ulcers. Notably, the 62-year-old patient also developed DVT and faced mobility challenges, being unable to walk by 12 months postoperation.

Regarding the time to achieve fusion, the distribution was as follows: seven (22.6%) participants achieved fusion at 3 months, 13 (41.9%) participants at 6 months, seven (22.6%) participants at 9 months, and two (6.5%) participants at 12 months. No statistically significant difference was observed in the time to

Figure 5



Weight-bearing patterns following tibio-talo-calcaneal arthrodesis. Related-samples Wilcoxon signed-rank test was used.

fusion between the type I DM and type II DM groups (*P*=0.37) (Table 2 and Fig. 4).

Rehabilitation pattern following tibio-talo-calcaneal arthrodesis

In our study, we investigated the time to start weight bearing and the use of orthosis during the recovery period following tibio-talo-calcaneal arthrodesis. Patients were instructed to start with toe-touch partial weight bearing in the first 2 weeks after surgery. By 4 weeks, patients progressed to partial weight bearing with 50% of body weight, using a walker or crutches for assistance. The analysis of orthosis usage revealed that 70.0% of participants were using orthosis in the first month, whereas 36.7% were without orthosis. The median time to start full weight bearing was 1 month (interquartile range, IQR=1–2) with orthosis and 3 months (IQR=1–6) without orthosis (Fig. 5). For patients with type I diabetes, the median time to start full-weight bearing with orthosis was 1 month (IQR=1–3), and for patients with type II diabetes, it was 1 month (IQR=1–1.75). The median time without orthosis was 3 months (IQR=1–9) for type I diabetes and 2.5 months (IQR=1–5.25) for type II diabetes.

Discussion

Our study explored the efficacy of surgical intervention for diabetic Charcot ankle to enhance patient outcomes. Charcot arthropathy's management remains a topic of debate in the medical community. Several clinicians and researchers recommend nonsurgical treatments as primary interventions [8]. Nevertheless, our findings underscore the potential of our surgical method. We noted a 93.5% fusion rate, and a majority of patients began weight-bearing within a month postoperation. Both diabetes cohorts exhibited significant improvement in their AOFAS scores, demonstrating the broad effectiveness of tibio-talo-calcaneal arthrodesis. These findings are in line with Coughlin *et al.* [13], who observed posttreatment AOFAS score enhancements.

Furthermore, our study highlighted a marked AOFAS score elevation from an initial 17.4±2.37–81.9±11.5 12 months posttreatment. This contrasts with El-Mowafi *et al.*'s [17] method where they used an intramedullary nail combined with an external fixator and recorded an AOFAS score increase from 34.6 to 66.4 over ~3 years. Similarly, Bajuri YM *et al.* [18] utilized a hindfoot arthrodesis nail technique, witnessing an AOFAS score jump from 16.28 to 84.10 over 2 years.

Our findings indicated complications in 38.7% of the patients, encompassing DVT, sepsis, and nonunion, underscoring the need for judicious patient selection and effective perioperative management. A notable case of Methicillin-resistant *Staphylococcus aureus* infection reaffirms the imperative for stringent postoperative infection control measures. Such observations echo Pawar *et al.* [19] study which evaluated patients treated with antibiotic-coated nails for ankle-related infections. While they reported complete infection eradication, the call for larger-scale studies persists.

In our analysis of diabetes types, we observed subtle distinctions. While baseline AOFAS scores were similar between type I and type II diabetes groups, the latter showed slightly improved results. Elevated presurgical HbA1c in type I patients underscores the importance of blood sugar control postsurgery. This is supported by literature indicating the critical role of glycemic control in postoperative outcomes [20]. Our study revealed a three-fold risk increase in high HbA1c patients.

Achieving optimal surgical fixation in tibio-talo-calcaneal arthrodesis is essential, even amidst challenges. Success hinges on maintaining anatomical alignment and protective measures [21,22]. However, concerning nonunion rates post tibio-talo-calcaneal arthrodesis are reported surpassing 15% [21,23]. Our findings emphasize the potential of tibio-talo-calcaneal arthrodesis. The stability achieved using a retrograde locking intramedullary nail is pivotal. This technique promotes early weight bearing and recovery [9,10].

The occurrence of nonunion in two male patients warrants attention. Nonunion refers to the failure of bone healing at the fusion site, resulting in persistent mobility and lack of bony union. In the context of tibio-talo-calcaneal arthrodesis with a retrograde locking nail, nonunion can be a significant complication that may require further intervention or revision surgery [24]. Furthermore, in the cohort studied by Pinzur, 19 (90.5%) out of 21 Charcot ankles achieved successful fusion. Radiological union was observed in 80% of the patients within an average follow-up period of 16 weeks. Notably, by the end of the most recent follow-up, all patients demonstrated the ability to walk independently. They either relied on a braceable limb or occasionally used assistive devices for mobility [25].

The study has several strengths, including a prospective design, adherence to strict inclusion and exclusion criteria, and the use of a validated functional outcome measure. In addition, the inclusion of a follow-up duration of 12 months provides valuable insights into the long-term effectiveness of the surgical solution using small incisions in Charcot patients. However, certain limitations should be acknowledged. The relatively small sample size may restrict the generalizability of the findings, but it aligns with the majority of cited studies involving diabetic patients. In addition, the absence of a control group for comparison is a limitation. A larger and more diverse cohort could offer additional insights and improve the statistical power of the study. Furthermore, longer-term follow-up beyond 12 months would provide a more comprehensive understanding of the surgical technique's durability and potential complications in the later postoperative period.

Conclusion

In conclusion, this case series provides preliminary evidence that tibio-talo-calcaneal arthrodesis using a retrograde locking intramedullary nail may be an effective surgical intervention for patients with Charcot ankle. While the results showed improved functional outcomes and high fusion rates in this subset of patients, the conclusions are limited by the small sample size and narrow focus on the ankle joint. It is important not to overgeneralize these findings to all Charcot ankle, as that would involve a wider range of patients and joint pathologies. Careful patient selection and individualized rehabilitation remain important to optimize outcomes. Further research with larger, multicenter studies is warranted to better elucidate the efficacy of this technique for different Charcot joints and long-term results. Overall, this study provides early data to support the potential of tibio-talo-calcaneal arthrodesis for diabetic Charcot ankle, but continued investigation is critical before applying the conclusions more broadly to other diabetic Charcot joints. A holistic, patient-centered approach combining thorough research and clinical experience will be key to advancing the management of this complex condition.

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Conflicts of interest

There are no conflicts of interest.

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