Original Article
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# Outcomes of Tibiotalocalcaneal Arthrodesis in Hindfoot Charcot Neuroarthropathy According to Coronal-Plane Deformity and Talar Osteolysis

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**Background:** Patients with severe hindfoot Charcot neuroarthropathy may experience various complications following tibiotalocalcaneal arthrodesis. Therefore, it is crucial to establish appropriate treatment plans to prevent potential complications and predict prognosis before surgery. This study aimed to investigate the impact of the degree of preoperative deformity in hindfoot Charcot neuroarthropathy on the outcomes of tibiotalocalcaneal arthrodesis.

**Methods:** Twenty patients who underwent tibiotalocalcaneal arthrodesis for hindfoot Charcot neuroarthropathy were grouped by the severity of their deformities into a mild deformity group (tibiotalar angle between 80° and 100° with minimal or no talar osteolysis) and a severe deformity group (tibiotalar angle < 80° or > 100°, or severe talar osteolysis precluding tibiotalocalcaneal arthrodesis and necessitating tibiocalcaneal arthrodesis). Their demographics, comorbidities, and various surgical outcomes were compared between the 2 groups. Additional analyses were conducted to determine the factors associated with poor clinical outcome, defined as the inability to achieve independent ambulation or the need for below-knee amputation.

**Results:** There were no significant differences in demographics and comorbidities between the 2 groups. Postoperative clinical outcomes, including the rate of postoperative infection and poor clinical outcome (inability to walk independently or having undergone below-knee amputation), showed no significant differences between the 2 groups. In terms of radiological outcomes, the bony union rates were 66.7% in the mild deformity group and 54.5% in the severe deformity group, with no significant difference. Similarly, other radiological outcomes, such as postoperative malalignment and time to union, did not vary significantly between the 2 groups. Factors associated with poor clinical outcome were the presence of preoperative infected wound and postoperative infection.

**Conclusions:** The severity of preoperative coronal deformity or talar osteolysis was not associated with clinical or radiological outcomes of tibiotalocalcaneal arthrodesis for hindfoot Charcot neuroarthropathy. However, preoperative infected wound and postoperative infection were associated with poor clinical outcomes. Therefore, instead of early amputation in cases of severe coronal deformity or insufficient talar bone stock, limb salvage with tibiotalocalcaneal arthrodesis may be a viable alternative, with particular attention to patients with preoperative infected wound and postoperative infection.

**Keywords:** *Arthrodesis, Arthropathy, Charcot joint, Deformity, Neurogenic*

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Charcot neuroarthropathy (CN) is a debilitating disease characterized by bone destruction and joint subluxation; it leads to severe deformities of foot and ankle joints, resulting in ulceration and infection. Consequently, major amputation may be necessary. Such amputations are associated with disability and morbidity. Therefore, these deformities should be corrected, and plantigrade foot and ankle should be restored to prevent abnormal pressure distribution and ulcer formation.[1)]

Surgical candidates for reconstructive surgery often present with multiple medical comorbidities; as such, this procedure can cause various complications, including infections, nonunion, delayed ambulation, and subsequent limb amputation.[2,3)] Specifically, CN affecting the ankle or subtalar joint (hindfoot CN) shows worse prognosis than midfoot CN.[4)] Hence, prognosis should be determined before reconstructive surgery to make appropriate decisions regarding treatment options, which may include conservative treatment, reconstructive surgery, or amputation.

Several factors, including end-stage renal disease (ESRD), peripheral vascular disease (PVD), hindfoot CN, and a high American Society of Anesthesiologists (ASA) classification (> 2), are identified as indicators of poor prognosis in reconstructive surgery for CN.[4,5)] In addition to these factors, severe preoperative deformities, especially those in the coronal plane, or significant bony loss of the talus may present challenges in deformity correction. Consequently, patients with such severe preoperative deformities and insufficient bone stock may experience less favorable outcomes than those with milder deformities and adequate bone stock. However, few studies have directly compared the severity of preoperative deformities with postoperative outcomes.

This study was performed to assess the relationship of the severity of preoperative deformity with postoperative outcomes. In addition to preoperative deformity, other factors that might influence postoperative results were investigated.

## METHODS

Approval for this study was obtained from the Institutional Review Board of Asan Medical Center (IRB No. 2022-0796), and informed consent was obtained from all individuals participating in this study.

### Patients

Consecutive patients who underwent tibiotalocalcaneal (TTC) arthrodesis for hindfoot CN from March 2002 to February 2021 were retrospectively reviewed. Patients with concurrent midfoot CN, a follow-up period of < 2 years, or a history of previous ankle or subtalar arthrodesis were excluded. Thus, 20 patients were enrolled in this study. All patients had diabetes and were receiving medical treatment.

Surgical intervention was prescribed for patients who had hindfoot CN but did not respond to conservative treatments (such as bracing or casting) and developed ulcers or had impending ulcers. In cases where CN was in the acute stage according to Eichenholtz classification, casting or bracing was initially applied, and surgery was planned after their condition progressed to stage 2 or 3. For patients with preexisting wound or infection, a combination of treatments, including bracing, casting, debridement, and intravenous antibiotics, was applied to ensure that the clinical evidence of wound and infection was resolved. Surgery was scheduled only when no clinical signs of wound or infection were observed, and laboratory examinations, including white blood cell count, erythrocyte sedimentation rate, and C-reactive protein returned to normal levels.

### Surgical Procedure

In case of the 15 patients, a retrograde intramedullary (IM) nail was used for TTC arthrodesis. For 3 patients who had preexisting wounds in areas where a nail or an interlocking screw would be inserted (case no. 8 and 15) (Table 1) or was difficult to obtain adequate stability by retrograde IM nail due to insufficient bone stock (case no. 12), an alternative surgical method involving screws and plates was applied. In 2 cases in which the IM nail was insufficient to achieve adequate fixation because of severe deformities and bone defects, arthrodesis was performed using screws and external ring fixators (case no. 10 and 11).

### Clinical Evaluation

The following demographic data were collected from medical records: age, body mass index (BMI), hemoglobin A1c (HbA1C) levels, the duration from diabetes diagnosis to TTC arthrodesis, smoking status, ASA classification, presence of ESRD, PVD, preoperative history of infected wound, and occurrence of postoperative infection. PVD was defined as an ABI of < 0.9 or as less than 3-vessel runoff on lower extremity computed tomography angiography or interventional (invasive) angiography.[6-8)]

The patients were categorized using the following criteria to assess clinical outcomes, in line with previous research: “excellent” if they had no residual wounds and could walk using their regular footwear, “good” if they had no residual wounds but required a simple ankle brace or

**Table 1.** Patient Characteristics and Outcomes

| Case no. | Preoperative deformity | | Preoperative infected wound | Postoperative infection | Postoperative alignment (TTA, °) | Bony union | Outcome |
|---|---|---|---|---|---|---|---|
| | Coronal deformity (TTA, °) | Osteolysis of talar body | | | | | Excellent/good/poor |
| Mild deformity group | | | | | | | |
| 1 | Varus (82) | – | – | – | Neutral | + | Excellent |
| 2 | Varus (83) | – | – | – | Varus (85) | + | Excellent |
| 3 | Neutral (90) | – | + | + | Varus (85) | – | Poor; amputated |
| 4 | Varus (81) | – | + | – | Neutral | + | Excellent |
| 5 | Valgus (97) | – | – | – | Neutral | + | Excellent |
| 6 | Valgus (93) | – | – | – | Neutral | – | Good |
| 7 | Neutral (90) | – | – | – | Neutral | + | Excellent |
| 8 | Varus (83) | – | + | + | Neutral | – | Poor; amputated |
| 9 | Neutral (89) | – | – | – | Neutral | + | Excellent |
| Severe deformity group | | | | | | | |
| 10 | Varus (63) | – | + | – | Valgus (103) | – | Good |
| 11 | Varus (50) | + | – | + | Neutral | + | Excellent |
| 12 | Varus (61) | + | – | – | Neutral | + | Excellent |
| 13 | Valgus (118) | – | + | + | Valgus (101) | – | Poor; amputated |
| 14 | Valgus (122) | + | – | – | Valgus (107) | + | Excellent |
| 15 | Valgus (108) | + | + | + | Neutral | – | Poor; amputated |
| 16 | Valgus (110) | – | – | + | Neutral | + | Excellent |
| 17 | Varus (56) | + | – | – | Varus (76) | + | Excellent |
| 18 | Varus (46) | + | – | – | Neutral | – | Good |
| 19 | Varus (51) | + | – | – | Neutral | + | Excellent |
| 20 | Varus (82) | + | + | + | Neutral | – | Poor; amputated |

TTA: tibiotalar angle.

ankle–foot orthosis for walking, and “poor” if they were unable to walk independently or had undergone below-knee amputation (BKA).[9,10] All patients classified as “poor” clinical outcomes in this study underwent BKA.

**Radiologic Evaluation**

Weight-bearing radiographs, including anteroposterior (AP) and lateral views of the ankle, were obtained pre- and postoperatively at every outpatient follow-up visit. The osteolysis of the talus was assessed, and the tibiotalar angle (TTA) was measured with Cobb angles by drawing a line along the anatomic axis of the tibia and another line along the articular surface of the talus (Fig. 1) to determine the degree of deformity preoperatively.[11,12] Cases were classified into the severe deformity (SD) group (Fig. 1A) when the TTA was < 80° or > 100°, or when severe talar osteolysis precluded adequate preparation of the tibiotalar or subtalar joints and stable fixation for TTC arthrodesis, thus requiring tibiocalcaneal arthrodesis. Cases with a TTA between 80° and 100° and minimal or no talar osteolysis, providing sufficient bone stock for stable fixation in TTC arthrodesis, were included in the mild deformity (MD) group (Fig. 1B).[11,12]

The presence of bony union was assessed using

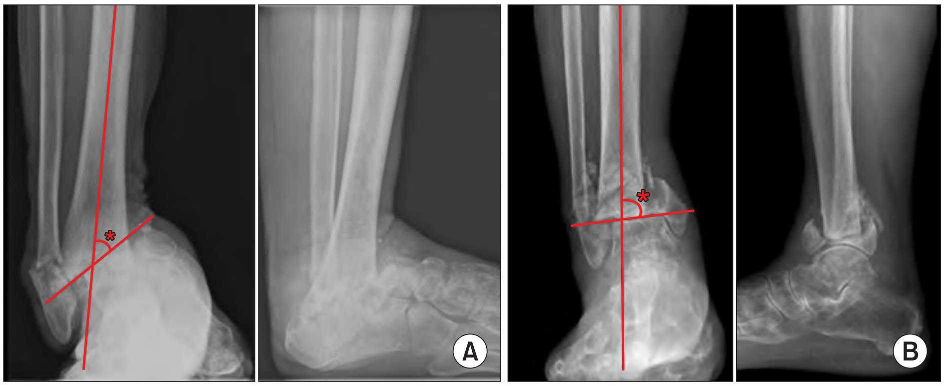


**Fig. 1.** Preoperative anteroposterior and lateral radiographs of the weight-bearing ankle for the measurement of the tibiotalar angle (asterisks) and assessment of the osteolysis of the talar body. (A) Severe coronal deformity with significant osteolysis of the talar body (severe deformity group). (B) Nearly normal tibiotalar angle and no loss of the talar body (mild deformity group).

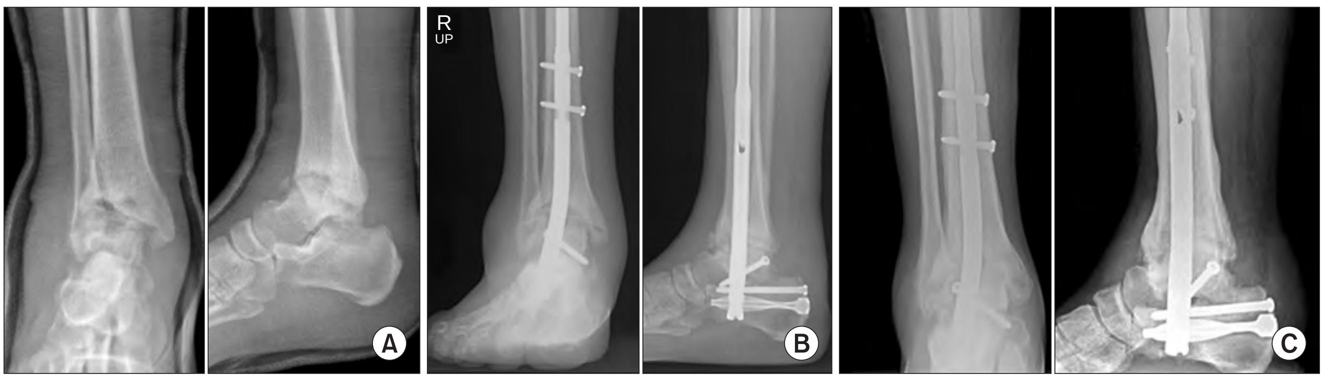


**Fig. 2.** Pre- and postoperative anteroposterior and lateral radiographs of the ankle of a 54-year-old male patient who underwent tibiotalocalcaneal arthrodesis with a retrograde intramedullary nail. (A) Severe valgus deformity without significant bony loss of the talar body. (B) Anteroposterior and lateral radiographs of the weight-bearing ankle 3 months postoperatively. (C) Bony union was observed on the anteroposterior and lateral radiographs of the ankle 6 months postoperatively.

postoperative radiographs. Bony union was defined as the obliteration of the joint space and trabecular continuity from the tibia to the talus on AP and lateral ankle radiographs (Fig. 2). Nonunion was determined when no radiographic evidence of union was evident more than 9 months after the surgery.[13] The extent of deformity correction was assessed by measuring the TTA from ankle AP radiographs taken 3 months postoperatively. When the TTA was within the range of 89° to 91°, the case was classified to have neutral alignment.[14] Conversely, cases that did not attain this range were categorized to have postoperative malalignment. The TTA was measured twice at an interval of 2 weeks by 2 foot-and-ankle orthopedic surgeons (SK and YC), and the average of 4 measurements was used.

**Statistical Analysis**

Data were statistically analyzed using SPSS Statistics for Windows version 28.0.1.1 (14; IBM Corp.). Descriptive statistics, including means, ranges, and percentages, were calculated. Differences in the mean follow-up period, age, BMI, HbA1C, duration from diabetes diagnosis to TTC arthrodesis, and interval from surgery to union between the 2 groups (MD vs. SD group) were assessed using Student *t*-test. Fisher's exact test was used for categorical variables, including smoking status, high ASA classification (> 2), presence of ESRD, PVD, preoperative history of infected wound, occurrence of postoperative infection, postoperative malalignment, bony union, and poor clinical outcome.

The patients were further evaluated to identify factors influencing poor clinical outcomes. They were divided into 2 groups based on clinical outcomes: excellent/good and poor. Logistic regression analysis was conducted; however, for variables with a frequency of 0, which made the calculation of odds ratios impossible, Fisher's exact test was applied instead. Data with $p \leq 0.05$ were considered significant.

## RESULTS

The patients' demographics and outcome data are summarized in Table 1. In this study, 9 patients were in the MD group, while 11 patients were in the SD group. Of the patients in the SD group, 3 had severe varus or valgus deformity alone (case no. 10, 13, and 16), and 1 had substantial talar osteolysis without severe coronal plane deformity and needed tibiocalcaneal arthrodesis (case no. 20). Furthermore, 7 patients had bony loss on the talus and severe malalignment on the coronal plane (Table 1). The mean follow-up time, age, BMI, HbA1C, and duration of DM before TTC arthrodesis did not significantly differ between the 2 groups (MD vs. SD group). The proportion of smoking, CKD, high ASA classification (> 2), PVD, and history of preoperative infected wound did not significantly vary between the 2 groups (Table 2). Postoperative outcomes, including postoperative infection, malalignment, bony union rate, time to union, and rate of poor clinical outcome (unable to walk independently or had undergone BKA), had no significant differences between the 2 groups (Table 3).

The group with excellent/good clinical outcomes was compared with the group with poor clinical outcomes. The results showed a significantly higher incidence of preoperative infected wound and postoperative infection in patients with poor clinical outcome compared to those with excellent or good clinical outcome ($p = 0.001$ and $p = 0.001$, respectively). Conversely, other patients' demographics, the severity of preoperative deformities, or the presence of postoperative malalignment did not significantly differ between the 2 groups (Table 4).

In this study, 5 patients underwent BKA following TTC arthrodesis, and they were classified to have poor clinical outcomes. Patient number 3 in the MD group and patient number 15 in the SD group underwent TTC arthrodesis with a retrograde IM nail and screws with plates, respectively; however, they developed wound necrosis and infection shortly after their surgeries. Although they had multiple debridement and received antibiotics, they eventually needed BKA. Patient no. 8 in the MD group underwent TTC arthrodesis with screws and plates. Nonunion was observed after the surgery; after 1 year, a revision TTC arthrodesis was performed using a femoral head allograft as a structural bone graft. However, because of the recurrence of surgical site infection, BKA was ultimately performed. Patient number 13 in the SD group had an infected heel wound before surgery and consequently underwent TTC arthrodesis with a retrograde IM nail; this patient experienced heel wound recurrence 3 months postoperatively. This recurrent condition was addressed by consulting plastic surgeons and covering the wound with a free flap. However, the free flap failed, and BKA was performed 5 months after the initial surgery. Lastly, patient number 20 in the SD group had CN reconstruction with a retrograde IM nail; as a result, fibrous union was achieved, and the patient could walk with the help of a simple ankle brace. However, 4 years after the surgery, the patient's wound and infection in the heel recurred even without any preceding factors such as trauma; as such, BKA was performed (Table 1).

**Table 2.** Comparison of Demographic Data between Mild and Severe Deformity Groups

| Variable | Mild deformity (n = 9) | Severe deformity (n = 11) | *p*-value |
|---|---|---|---|
| Mean follow-up (mo) | 52.1 | 64.3 | 0.341 |
| Mean age (yr) | 54.2 | 59.6 | 0.353 |
| Mean BMI (kg/m$^2$) | 23.9 | 24.3 | 0.797 |
| HbA1C at time of surgery (%) | 8.2 | 8.5 | 0.716 |
| Duration of diabetes (yr) | 24.3 | 17.4 | 0.137 |
| Smoking | 1 (11.1) | 3 (27.3) | 0.591 |
| CKD | 8 (88.9) | 6 (54.5) | 0.157 |
| High ASA classification (> 2) | 8 (88.9) | 8 (72.7) | 0.591 |
| PVD | 4 (44.4) | 9 (81.8) | 0.160 |
| Preoperative infected wound | 3 (33.3) | 4 (36.4) | > 0.999 |

Values are presented as number (%) unless otherwise indicated.
BMI: body mass index, HbA1C: hemoglobin A1c, CKD: chronic kidney disease, ASA: American Society of Anesthesiologists, PVD: peripheral vascular disease.

**Table 3.** Comparison of Radiological Parameters and Surgical Outcomes between Mild and Severe Deformity Groups

| | Mild deformity (n = 9) | Severe deformity (n = 11) | *p*-value |
|---|---|---|---|
| Postoperative infection | 2 (22.2) | 5 (45.5) | 0.374 |
| Postoperative malalignment | 2 (22.2) | 4 (36.4) | 0.642 |
| Bony union | 6 (66.7) | 6 (54.5) | 0.670 |
| Interval to union (mo) | 5.9 | 7.3 | 0.403 |
| Clinical outcome; poor | 2 (22.2) | 3 (27.3) | > 0.999 |

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

**Table 4.** Factors Associated with Clinical Outcomes: Logistic Regression and Fisher's Exact Test

| Variable | Excellent or good (n = 15) | Poor (n = 5) | Odds ratio | 95% CI | *p*-value |
|---|---|---|---|---|---|
| Mean age (yr) | 56.1 | 60.2 | 1.029 | 0.944–1.121 | 0.519 |
| Mean BMI (kg/m$^2$) | 24.2 | 23.7 | 0.955 | 0.689–1.325 | 0.785 |
| HbA1C at time of surgery (%) | 8.8 | 7.1 | 0.839 | 0.687–1.025 | 0.086 |
| Duration of diabetes (yr) | 23 | 13 | 0.429 | 0.154–1.196 | 0.106 |
| Smoking | 3 (20.0) | 1 (20.0) | 1.000 | 0.08–12.557 | > 0.999 |
| CKD | 10 (66.7) | 4 (80.0) | 2.000 | 0.174–22.949 | 0.578 |
| High ASA classification (> 2) | 12 (80.0) | 4 (80.0) | 1.000 | 0.08–12.557 | > 0.999 |
| PVD | 9 (60.0) | 4 (80.0) | 2.667 | 0.237–30.066 | 0.428 |
| Preoperative infected wound* | 2 (13.3) | 5 (100.0) | - | - | 0.001 |
| Preoperative severe deformity | 8 (53.3) | 3 (60.0) | 1.312 | 0.168–10.264 | 0.796 |
| Postoperative infection* | 2 (13.3) | 5 (100.0) | - | - | 0.001 |
| Postoperative malalignment | 4 (26.7) | 2 (40.0) | 1.834 | 0.219–15.335 | 0.576 |

Values are presented as number (%) unless otherwise indicated.
BMI: body mass index, HbA1C: hemoglobin A1c, CKD: chronic kidney disease, ASA: American Society of Anesthesiologists, PVD: peripheral vascular disease.
*Fisher's exact test, statistically significant.

## DISCUSSION

With the promising results of reconstructive surgery for hindfoot CN, TTC arthrodesis has become a relatively common procedure. However, the challenges presented by CN patients with various comorbidities, including diabetes, impaired immunity, vitamin D deficiency, and poor bone quality, have raised concerns about complications related to reconstructive surgery. These complications may include infections, nonunion, delayed ambulation, and even limb amputation in severe cases.[2,3,15] Since unsuccessful reconstruction can result in disabling outcomes, treatment options should be carefully considered before surgery. To address this concern, we aimed to analyze the factors influencing the outcomes of hindfoot CN reconstructive surgery, specifically TTC arthrodesis. During the planning phase of our study, we hypothesized that the degree of deformity and the extent of bony loss might affect radiological or clinical results. However, our study revealed that the degree of preoperative deformity or bony loss was not significantly associated with surgical outcomes. One intriguing finding from our study was that TTC arthrodesis resulted in less favorable surgical outcomes for patients who had a preoperative infected wound even after the clinical evidence of wound and infection was resolved through various preoperative managements.

Harkin et al.[9] investigated the effect of preoperative deformities on clinical outcomes in hindfoot CN and found that preoperative deformities (either coronal or sagittal) are not related to clinical outcomes. These results are consistent with our findings. Furthermore, their study and our study showed that postoperative alignment is not correlated with surgical outcomes. However, unlike our study, their investigation did not find any substantial variation in surgical outcomes for patients with a history of preoperative infection.[9] We also included cases involving severe preoperative bony loss of the talus, in addition to angular deformity, in the analysis and found no significant differences in surgical outcomes. Similarly, Aikawa et al.[16] reported favorable outcomes by performing TTC arthrodesis by using a locking plate in patients with severe talar body loss because of CN. Thus, reconstruction should be considered even in cases with severe preoperative deformities or extensive talar body osteolysis.

Several studies have been performed to investigate the risk factors associated with hindfoot CN reconstruction. McCann et al.[4] performed a systemic review and found that ESRD, PVD, hindfoot CN, and reconstruction during an active-phase Charcot process are associated with unfavorable outcomes. Sundararajan et al.[17] reported that the Eichenholtz stage is not associated with the outcome of hindfoot arthrodesis. Rettedal et al.[18] suggested a prognostic scoring system for patients undergoing CN reconstructive surgery by collecting patients' age, BMI, presence of wound or osteomyelitis, anatomic location, disease activity, and HbA1C. In the present study, among the 5 patients who had both preoperative infected wound and postoperative reinfection, all underwent major amputation (cases 3, 8, 13, 15, and 20 in Table 1). In contrast, patients with either preoperative infected wound alone (cases 4 and 10) or postoperative infection alone (cases 11 and 16) demonstrated excellent or good clinical outcomes (Tables 1 and 4). Notably, among the patients who underwent major amputation, 2 experienced skin necrosis and infection shortly after surgery, whereas the remaining 3 developed infections several months to several years later (ranging from 3 months to 4 years). These findings suggest that clinical failure was not solely attributable to inadequate preoperative infection and wound control. Instead, multiple factors appear to have contributed to the poor clinical outcome. Therefore, a more cautious approach is recommended to those patients who have a history of preoperative infected wound and postoperative infection. Alternatively, early consideration of amputation to accelerate postoperative rehabilitation and maintain walking ability may provide more favorable outcomes for such patients.

According to many studies reporting outcomes of CN reconstruction, surgery is typically delayed during the acute stage, with reconstruction generally performed at Eichenholtz stage 2 or 3.[19-24] McCann et al.[4] reported that cases undergoing reconstruction during the active phase of CN had a higher rate of amputation compared to those in which reconstruction was performed during the quiescent phase. In contrast, Caravaggi et al.[25] introduced the term "early chronic stage," corresponding to late Eichenholtz stage 1 or early stage 2, and reported favorable outcomes when reconstruction was performed during this phase of CN. Similarly, Simon et al.[26] reported favorable outcomes with anatomical realignment performed in early midfoot CN at Eichenholtz stage 1. Several studies assessing the surgical outcomes of reconstruction based on the stages of CN have shown no association between CN stage and surgical outcomes.[17,18] As described above, despite the numerous studies, there remains a lack of consensus regarding the optimal timing for surgical reconstruction of CN.[27] In our study, we delayed surgical reconstruction during the acute stage, performing the procedure after patients had progressed to stage 2 or 3, as determined by clinical findings and weight-bearing radiographs. Although several studies have suggested laboratory tests including bone turnover markers that reflect the acute stage, we did not include these in our research. However, utilizing such markers could enhance the accuracy of staging and be beneficial in establishing the appropriate timing for the surgery.[28,29]

Various methods for hindfoot CN reconstruction have been proposed over time; more recently, the widespread adoption of retrograde IM nails has been associated with favorable outcomes.[20] However, the superiority of each fixation method has been debated. While certain studies have reported the advantages of IM nails to EF,[19,30] controversial results of both surgical approaches have emerged in some instances.[31,32] In 1 review article, surgical principles include minimizing soft-tissue trauma, meticulously preparing joints, correcting deformities, and ensuring appropriate stability rather than choosing a fixation method.[1] In the present study, various fixation methods, including retrograde IM nails, screws with plates, and screws with external ring fixators, were utilized to reconstruct hindfoot CN and for these reasons described above, patients undergoing TTC arthrodesis with various fixation methods were enrolled in this study.

This study has a few limitations. The number of cases is limited and data are heterogenous because of the rarity of the disease (hindfoot CN) and the challenges associated with poor patient compliance that makes long-term follow-up difficult. Consequently, this heterogeneity may negatively affect statistical analysis and result interpretation. Additionally, since this study is retrospective, information may be insufficient. As such, further large-scale, multi-center, prospective studies should be performed.

In conclusion, the severity of preoperative deformity or bony loss of the talus was not associated with the clinical and radiological outcomes of hindfoot CN reconstruction. Therefore, rather than considering early amputation in the presence of severe preoperative coronal plane deformity or insufficient talar bone stock, a limb salvage approach with reconstruction may provide a favorable alternative. Additionally, a preoperative history of infected wound along with postoperative reinfection, may be associated with poor clinical outcome, indicating the need for more careful approach for these patients.

## CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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