The use of retrograde intramedullary femoral nail for tibiotalocalcaneal fusion in charcot ankle & foot joints

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Introduction
Charcot arthropathy is a destructive inflammation, which may affect any joint, especially joints of the ankle and foot. Bony fragmentation, fracture, and dislocation will progress to deformity, bony prominence, and instability. This often causes ulceration and deep infection that may necessitate amputation. The objective of the study is to assess the results of treating Charcot ankle with fusion by retrograde intramedullary femoral nail.
Patients and methods
Twenty patients were prospectively studied, all of them were clinically diagnosed to have Charcot ankle arthropathy. Preoperative Assessment of all patients by the American Orthopedic Foot and Ankle Scale (AOFAS) was done. In postoperative follow up, the modified AOFAS score was used with a maximum score of 86, as hind foot motion and ankle motion were blocked by arthrodesis.
Results
Significant improvement in functional score for the series' patients was encountered. There is increase in the mean score from 33.6 to 73.2 (P<0.001), which considered clinically and statistically significant.
Conclusion
Tibiotalocalcaneal arthrodesis with retrograde intramedullary nail is a successful method for ankle fusion with good clinical and functional scores.

Keywords:
charcot ankle arthropathy, intramedullary femoral nail, retrograde, tibiotalocalcaneal fusion

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Introduction

Charcot arthropathy of the foot and ankle is a condition associated with neuropathy characterized by bone and joint fragmentation and destruction that may result in severe deformities. The foot shows swelling, warmth, and erythema and may be difficult initially to distinguish from infection. Bony fractures and ligamentous laxity develop resulting in joint dislocation and followed with hypertrophic repair. Resultant Bone and joint destruction will affect shoes and braces wear. This may result in skin ulceration, soft tissue infection and osteomyelitis, which may necessitate amputation of the affected limb [1].

In 1868, Jean-Martin Charcot published a description of severe osteoarthritis associated with tabes dorsalis. Later, other causes of neuropathic arthropathy were recognized, as poliomyelitis, syringomyelia and diabetes mellitus. As a result of effective treatment of syphilis and increased life span of diabetics associated with the discovery of insulin, diabetes is now the most common cause of Charcot arthropathy [2].

Reconstruction with tibiotalocalcaneal (TTC) fusion may be undertaken with the aim of reducing the risk of ulceration by creating a stable plantigrade foot allowing the patient to bear weight and mobilize, thereby decreasing the morbidity and the risk of amputation [3].

TTC fusion has been reported with different methods of fixation [4], such as Steinmann pins, screws, staples, plates, angled blade plates [5], external fixators, and intramedullary nails [6]. The achievement of a stable fusion is mandatory but difficult with conventional plates, screws, and pins due to associated poor bone quality and extensive soft tissue and bone loss that accompanies the disease [7]

Nails have been shown to have higher bending stiffness, increased rotational stability, and higher dynamic compression capability than crossed lag screws, external

fixators, and blade plates [8–11]. The aim of the study is to assess the clinical and radiological results of TTC fusion using retrograde intramedullary femoral nail in Charcot joint of the foot and ankle. Our hypothesis is that retrograde femoral nail is a cheap option that can provide rigid distal fixation because of multiple distal locking screws. So, it is a successful option in managing those patients in comparison with the more expensive tibiotalocalcaneal nails.

Patients and methods

This is a prospective case series study. It included patients who were diagnosed to have Charcot ankle arthropathy with instability, deformity and failed conservative methods of treatment. The exclusion criteria were skeletally immature patients, patients with severe bone loss, and associated severe vascular compromise or severe soft tissue injury. Also, cases of active infection were excluded.

Twenty-nine cases presented to our center during the period between December 2017 and March 2020. Nine cases were excluded. Five cases had uncontrollable severe infection, four cases had very poor skin condition and one case with severe peripheral vascular disease. The remaining 20 cases were included. They were clinically diagnosed to have Charcot ankle arthropathy secondary to insulin-dependent diabetes mellitus. The study was conducted after taking approval from the scientific board and the ethical committee of our department. An informed consent was taken from all patients before participating in the study.

The mean age was 53±±8.96 years. The mean follow up time was 15 months (Range; 12–24 months). All patients were in a quiescent condition of their ankles, Eichenholz III mainly and Eichenholz II. From the 20 ankles, eight ankles were in valgus, six ankles were in varus, two ankles were neutral, three ankles were in equinovarus, and one ankle was flail. Seven patients had previous ankle surgeries; two had failed previous arthrodesis with screws, one had ankle debridement for severe infection and external fixator application and four had previous surgeries for skin ulcers, infection, breakage and/or osteomyelitis.

All patients were evaluated preoperatively with full history taking including predisposing factors as diabetes onset, course, duration, and type of diabetes if insulin-dependent or not. Also, the history of other neurological problems and medications of other chronic illness were collected. Finally, history was taken for any previous trauma, operations, casting or special ankle orthosis.

Thorough examination was done including the ankle stability tests as valgus and varus stress tests, evaluation of any ulcer present and proper vascular examination was performed.

Laboratory preoperative investigations were done. Patients were considered ready to be operated upon when CRP and ESR levels were not markedly increased, to be sure that there is no active infection. Without infection there could be mild to moderate elevation in ESR and CRP in Charcot arthropathy. With ESR levels above 70, and or double fold increase in CRP level, we were cautious because there was suspicion of active osteomyelitis. Our target in HbA1c adjustment was to be below 6.5.

Plain radiography of ankle and foot were done. This was important to assess the bone quality, joint congruity or deformity and presence of any sequestrum around the ankle. In addition, doppler ultrasound examination for assessment of the vascularity of that ankle was done.

Preoperative evaluation of all patients was done using the American Orthopedic Foot and Ankle society score (AOFAS). It covers four anatomic regions of foot and ankle: The ankle hind foot, midfoot, metatarsophalangeal (MTP)-interphalangeal (IP) for the hallux, and MTP- IP for the lesser toes. Each tool was designed to be used independently of the others. We used the part for ankle-hindfoot with total score of 100 points, comprised of nine questions and covers three categories: Pain (40 points), Function (50 points), and alignment (10 points). In postoperative follow up we use the modified AOFAS score, with a maximum score of 86 as hind foot motion and ankle motion were blocked by arthrodesis.

A score of 74 to 86 was considered an excellent result, 64 to 73 a good result, 54 to 63 a fair result, and <54 a poor result. Operation was done using retrograde intramedullary femoral nail.

Surgical technique

Patients were positioned supine position on a radiolucent table. Two or three blankets can be placed on the table under the patient's operated leg to provide a leveled work area. The leg could usually be rotated enough to allow medial access when needed.

Direct lateral incision over anterior border of fibula was performed; thorough debridement of any synovial or diseased soft tissue was done. Any old ulcer to be excised in block until healthy tissue reached (Fig. 1). Sclerosed and sequestrated bone fragments were also removed. The lateral malleolus was transected with the

Figure 1

Intraoperative images showing incision and joint debridement.

oscillating saw and was used as graft. Once the lateral ankle joint was exposed, the surgical removal of joint cartilage is straightforward. The medial malleolus was not excised; only removal of its cartilage was performed to enhance bony fusion.

The foot was then placed in approximately 5° of dorsiflexion and in neutral to 5° of valgus, and rotation was aligned with the opposite limb. Alignment was checked with the tibial shaft lying in line with base of 2nd metatarsal. Talar dome cut was then performed using the saw. Roughening of posterior part of distal tibia and upper surface of posterior part of calcaneus was done using the saw. Once joint surfaces preparation was performed, nail insertion was done through plantar incision. Incision could be done either horizontal or vertical, however the vertical incision allows better visualization and access to nail starting point. Medial incision was utilized whenever indicated. The nail was inserted in a way to allow the distal locking screws to be in a near posterior-to-anterior direction.

Postoperatively, the patients were further supported in either a posterior below-the-knee slab or ankle foot orthosis for 8–12 weeks according to progress of union. Follow up visits were arranged every 2 weeks for the first month and monthly subsequently. At every visit, the patients were examined clinically for wound healing, the neurovascular state of the limb, and evidence of any infection. Radigraphy were obtained (and repeated with every follow up visit) to check for alignment at the ankle region and the progress of bone healing.

The clinical results were determined using the modified American Orthopedic Foot and Ankle Society ankle hindfoot scale. The modified score (and score percentage) was calculated for all patients at 3 & 6 months post-surgery as well as a final score calculated at last follow up.

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0 (Armonk, NY: IBM Corp). [12] *P* value <0.05 was considered statistically significant, while *P* value <0.01 was considered as statistically highly significant and *P* value <0.001as statistically very highly significant [13]. The used tests were Post Hoc Test which is used to analyze the significance between the different stages and Wilcoxon signed ranks test, which is used for abnormally distributed quantitative variables, to compare between two periods.

Results

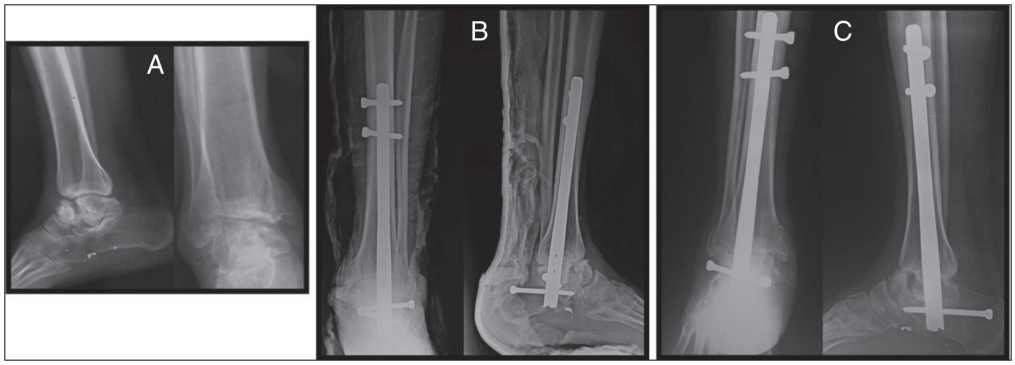
The mean operative time was 2.49 h. A medial incision was mandatory in two of our patients, one because there was previous incision on the medial side, and the second because bad skin condition on the lateral side of ankle. It was made longitudinally along the anterior margin of the medial malleolus. This allowed access into the medial gutter, to remove the cartilage and fibrous tissue, and permited the use of the saw to remove the appropriate amount of medial malleolus needed to gain alignment and contact. Tibialis posterior muscle tendon could be damaged during this step. However, it would be of little functional importance because of state of neuropathic arthropathy present. Osteotomy of the medial malleolus would help medialization of the talus and foot if it was needed for better axial alignment. Retrograde intramedullary femoral nails were used in all cases.

Union was assessed both clinically and radiologically. Delayed union was defined as failure to obtain union by 30 weeks, with eventual achievement of union by 40 weeks without surgical interference. Nonunion was defined as failure to obtain sound union by 40 weeks postoperatively requiring further surgical interference [11]. Twelve patients (60%) had complete union (Figs. 2 and 3), six patients (30%) were non-united,

Figure 2

A patient with Charcot arthropathy. a)Preoperative, b) postoperative and c) Radiography at the end of follow up showing complete union. d) clinical photos of the patient after union.

Figure 3



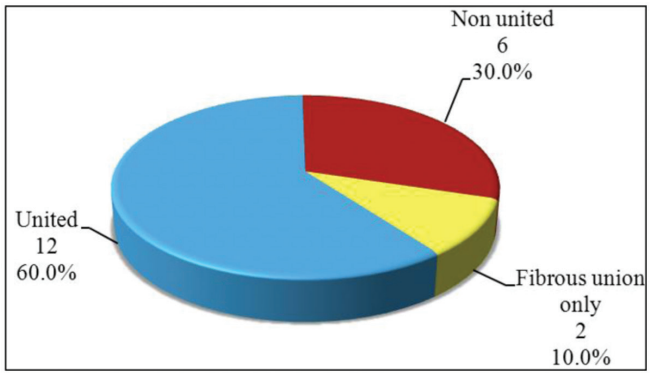
A patient with Charcot arthropathy. a) Preoperative, b) postoperative and c) radiography at the end of follow up showing complete union.

and two patients (10%) were having stable fibrous union (Fig. 4). Mean time to union was 6.79 months (Range; 3-8 months).

The mean preoperative score percentage was 33.6% (range 20–52). This showed some improvement 3 months after surgery with mean score percentage of 58% (range 32.6–67.4); (P<0.05). There was further improvement in score at 6-months post-surgery. Mean score percentage at this point was 76.3% (range 45.4–89.5) (P<0.001). The mean final score percentage at the end of study was 85.1% (range 65.1–94.2) (P<0.001) (Table 1).

Nine patients (45%) developed complications. Two patients had intraoperative peri-implant fractures (cracks) in shafts of tibia during nail introduction. One of them the crack was distal (near ankle joint) and so required no further management but a longer duration of non- weight - bearing. The other patient, the crack was more proximal, so the nail had to be changed to a

Figure 4



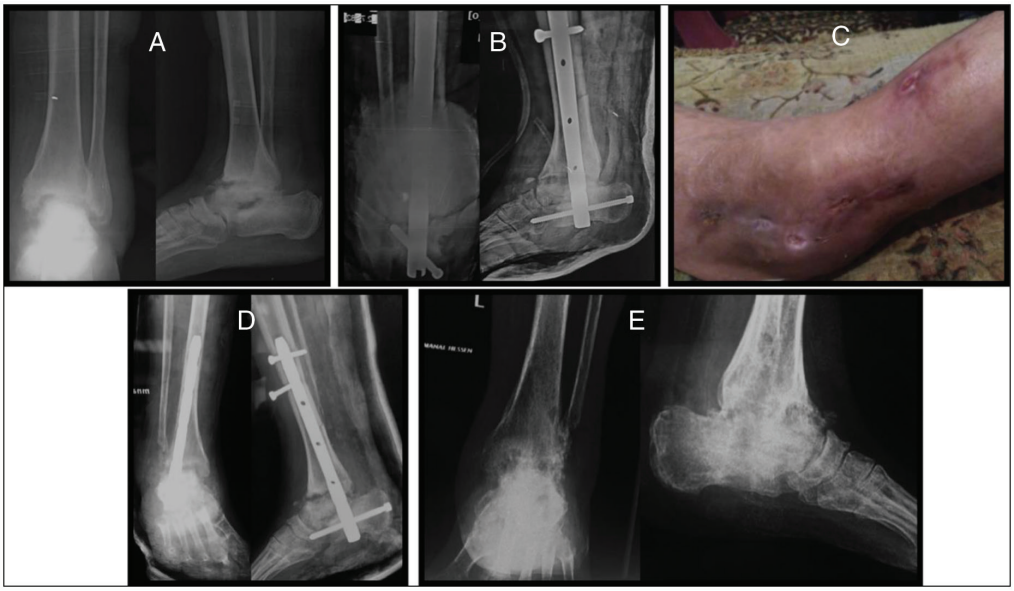
Distribution of the studied cases according to union (n=20).

Table 1 Comparison of AOFAS ankle-hindfoot score before and after surgery (*n*=20).

Total score	Preoperative	At 3 months	At 6 months	Final (mean 15 months)
Total				
Min- Max	20–52	28–58	39–77	39–81
Mean SD	33.6±8.65	49.85±8.77	65.65±9.26	73.15±6.61
Median	33.5	54	67	71.5
Fr. (p)		55.203(<0.001)*		
Sig. Bet. Periods		P_1=0.049*, P_2<0.001*, P_3<0.001*		
%	/100%	/86%	/86%	/86%
Min-Max	20–52	32.56–67.44	45.35–89.53	45.53–94.19
Mean±SD	33.6±8.65	57.97±10.2	76.34±10.77	85.06±7.69
Median	33.5	62.79	77.91	83.14
Fr. (p)		52.239(<0.001)*		
Sig. Bet. Periods		P_1=0.027*, P_2<0.001*, P_3<0.001*		

Fr.= Freidman test, P=*P* value, Sig.Bet. Periods= Significance between periods (was done using Post Hoc Test [Dunn's]), P_1= *P* value for comparing between preoperative and after 3 months, P_2=*P* value for comparing between preoperative and after 6 months, P_3=*P* value for comparing between preoperative and final, *=Statistically significant.

Figure 5



(a) Preoperative and (b) immediate postoperative radiography for a patient with charcot ankle treated with TTC fusion. (c) clinical images showing infection around proximal locking screws and (d) radiography showing loosening of proximal locking screws. (e) Radiography after removal of the nail showing union.

longer one, which by-passed the fracture site by suitable distance. Weight bearing was also delayed for 2 months.

Seven patients had postoperative infections. Three patients had superficial skin infection improved with parenteral antibiotics and local wound care. Two patients had sepsis and loosening around the proximal screws mandating screws removal in one of them. For the sixth patient, the arthrodesis sites were almost united, so the nail removed with proper debridement and a walking cast applied (Fig. 5). Another patient had infection and ulceration at the site of distal screws. The ankle was united, so the nail was also removed.

Unfortunately, one of our patients developed severe uncontrollable infection with skin breakage around the surgical site. Extensive wound debridement, nail removal and negative pressure wound dressing partially controlled the infection. This patient had the worst score in our series with an unstable ankle and requested amputation after 6 months.

Discussion

Charcot arthropathy of the ankle is a challenging problem in orthopedics. It is a destructive process that can affect patients with peripheral neuropathy of any etiology. It can lead to significant long-term complications such as collapse of the bony architecture, ulcers, foot deformity, infection, and may eventually lead to amputation. In diabetic patients, the risk of amputation can reach 15%. Early diagnosis and

proper management are crucial to avoid catastrophic outcomes [11].

The surgical goal is to restore stability and alignment and achieve a plantigrade, weight bearing surface free of ulceration. Arthrodesis can achieve this goal and can be achieved with either external fixation or internal fixation methods. However, controversies remain regarding the most successful and reproducible method. The main disadvantage of external fixation lies in the requirement for long unloading of the affected extremity, which causes muscular atrophy and lack of patient compliance in such device. Internal fixation enables full weight- bearing after 6 weeks postoperatively and thus more rapid recovery [11,14].

Although there is general acceptance that timing of surgery has been reserved for Eichenholz coalescence or consolidative phases, Simon *et al*. [15] showed promising results with fusion during the fragmentation stage I with no major complications and return to regular shoe wear in a mean of 27 weeks.

Retrograde femoral nail was used in all cases of this series. The supracondylar femoral nails are cheaper with more screws available distally, thus providing better fixation.

Lee *et al*. [16] used curved nail and mentioned that no study in the published data compared TTC fusion with straight nail versus curved nail design, both designs appear to confer favorable functional outcome. Goebel *et al*. [17] reported significant improvement in the quality of life after TTC fusion using a straight nail construct.

Pinzur and Kelikian [18] on similar study used the supracondylar femoral nail and reported that all their 9 patients were ambulatory without localized pain and were clinically free of infection

Hammett *et al*. [19] studied over 52 ankle arthrodesis due to various causes. The nail used in their study was a curved humeral nail and they reported that TTC fusion with retrograde curved nail is an effective technique for combined ankle and subtalar arthrodesis in complex deformity and neuropathic ankles.

Several authors [20–24] reported on using straight nails for TTC fusion. Elgohary and Elghaffar [24], similar to our study, used supracondylar femoral nail and advocated using such nails as they provide better stability and less stress rising effect. They also advised regarding the nail length, better to extend beyond the isthmus of the tibia and they added that the proximal screws may be abandoned to allow compression through axial loading with weight bearing.

Brodsky *et al*. [23] mentioned that straight nail has both advantages and disadvantages. They can achieve better axial compression across both arthrodesis sites compared to curved nails. Besides, straight nails also don't have the tendency to deviate in coronal plane as might happen with axial compression along the curved nail. However, straight nails require more surgical skill to achieve alignment of the reconstruction including medialization of the calcaneus within the ankle mortise.

Regarding complications, Emara *et al*. [25] had 19% of their patients suffered from loosening, 14% had superficial infection and 11.9% had delayed union and required bone graft. Caixeta *et al*. [26] in their study on 29 patients found a 38% complication rate. They documented complications in the form of nonunion, infections, tibial fractures, and material failure.

Niinimaki *et al*. [27] reported 15% of complications in 34 patients; four postoperative infections with two patients in need for implant removal and one case of venous thrombo– embolism.

As the major cause of Charcot ankle is diabetes mellitus, Mendicino *et al*. [28] had compared TTC fusion with locked medullary nailing in 20 patients, 10 was non diabetic and 10 diabetic. They reported 5 out of the 10 diabetic patients to have major complications.

Elgohary and Elghaffar, [24] Ettinger *et al*. [29] and Lee *et al*. [30] had 5–6% of their patients needing amputation mostly due to deep infection. On the contrary, ElAlfy *et al*., [11] Siebachmeyer *et al*. [21] and Emara *et al*. [25] had no amputations with100% salvage rate. On the other hand, Chraim *et al*. [20] and Cravaggi *et al*. [31] reported low salvage rate of about 85%. This could be explained by advanced pathologies of their patients and the poor soft tissue pattern, with seven of their patients suffering preoperatively from ulcerations at time of initial presentations.

In this study complications rate was 45% (9 patients) and the rate of amputation in this study were 5%. Superficial and deep wound infection (3 and 4 patients respectively) represented the most common complication and were successfully managed in all except one case.

The rate of amputation in this study is fair (5%). Several factors contributed to prevent deep infection and avoid amputations. Preoperatively, patients had been chosen carefully to be free clinically and laboratory

from infection. Surgery was not performed except after adjustment of blood glucose level and only in Eichenholz phase II or III.

Regarding hardware complications, our study had 2 (10%) patients with intraoperative tibial peri-implant fractures which compares well with the results by Chraim *et al*. [20] (15.4%), ELAlfy *et al*. [11] (15.4%), Emara *et al*. [25] (31%), Ettinger *et al*. [29] (5.2%) and Seibachmeyer *et al*. [16] (23.8%).

Regarding union, 60% of our patients had their ankles fused successfully in addition to another 10% having stable fibrous union. Union of the fusion site varied across the literature with 60-100% union rates reported. [11,20, 21, 24, 25, 29].

AOFAS score for patients in this study shows significant improvement after TTC fusion after the follow up period (mean 15 months) with the mean score been increased from 33.60 to 73.2. Chraim *et al*. [15] had a mean postoperative AOFAS score of 71, ElAlfy *et al*. [11] had mean score of 75, Emara *et al*. [25] 71, Siebachmeyer *et al*. [21] 65, Elgohary and Elghaffar [24] 77 and Lee *et al*. [30] had mean score of 69.

There are several limitations to the present study including the small number of patients which can be accepted due to limited number who present with end stage hindfoot joints requiring such a salvage procedure. In addition, we only used AOFAS score for the ankle – hind foot and did not include other validated patient reported outcome scores such as the Foot and Ankle Outcome Score (FAOS) and the European Quality of Life – Five Dimensions questionnaire (EQ_ –5D), which might be more popular and more generalized.

Charcot ankle and foot need meticulous follow up all through all the patient's life. Any complications can be expected at any time and should be explained to the patient.

Conclusion

Tibiotalocalcaneal arthrodesis with retrograde intramedullary nail is a successful method for ankle fusion with good clinical and functional scores.

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Ethics review committee

This study has been approved by the appropriate ethics committee (the scientific board of the Department of Trauma and Orthopedic Surgery, Cairo university hospitals). Details that might disclose the identity of the subjects in the study have been omitted.

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Nil.

Conflicts of interest

None.

References

1 La Fontaine J, Lavery L, Jude E. Current concepts of Charcot foot in diabetic patients. Foot 2016; 26:7–14. doi: 10.1016/j.foot.2015.11.001

2 Gupta R. A short history of neuropathic arthropathy. Clin Orthop Relat Res 1993; 296:43–9.

3 Makrilakis K. Charcot Foot. In: Eleftheriadou L, Kokkinos A, Makrilakis, Tentolouris N, Tenotolouris A, Panagiostis, editors. Atlas of the Diabetic Foot. Chichester, UK: John Wiley & Sons, Ltd; 2019. p. 147–67. [cited 2019 Nov 16]. Available from: http://doi.wiley.com/10.1002/9781119255314.ch10

4 Carrier DA, Harris CM. Ankle arthrodesis with vertical Steinmann's pins in rheumatoid arthritis. Clin Orthop Relat Res 1991; 268:10–4.

5 Hanson TW, Cracchiolo A 3rd. The use of a 95 degree blade plate and a posterior approach to achieve tibiotalocalcaneal arthrodesis. Foot Ankle Int 2002; 23:704–10. doi: 10.1177/107110070202300805

6 Budnar VM, Hepple S, Harries WG, Livingstone JA, Winson I. Tibiotalocalcaneal arthrodesis with a curved, interlocking, intramedullary nail. Foot Ankle Int 2010; 31:1085-92. doi: 10.3113/FAI.2010.1085

7 Lee DJ, Schaffer J, Chen T, Oh I. Internal versus external fixation of charcot midfoot deformity realignment. Orthopedics. Slack Incorporated 2016; 39:e595–601.

8 Berend ME, Glisson RR, Nunley JA. A biomechanical comparison of intramedullary nail and crossed lag screw fixation for tibiotalocalcaneal arthrodesis. Foot Ankle Int 1997; 18:639–43. doi: 10.1177/107110079701801007

9 Berson L, McGarvey WC, Clanton TO. Evaluation of compression in intramedullary hindfoot arthrodesis. Foot Ankle Int 2002; 23:992–5. doi: 10.1177/107110070202301103

10 Alfahd U, Roth SE, Stephen D, Whyne CM. Biomechanical comparison of intramedullary nail and blade plate fixation for tibiotalocalcaneal arthrodesis. J Orthop Trauma 2005; 19:703–8. doi: 10.1097/01.bot.0000184142.90448.e3

11 ElAlfy B, Ali AM, Fawzy SI. Ilizarov external fixator versus retrograde intramedullary nailing for ankle joint arthrodesis in diabetic charcot neuroarthropathy. J Foot Ankle Surg 2017; 56:309–313. doi: 10.1053/j.jfas.2016.10.014

12 Kirkpatrick LA, Feeney BC. A simple guide to IBM SPSS statistics for version 20.0. Student ed. Belmont Calif.: Wadsworth, Cengage Learning; 2013.

13 Kotz SL, Campbell BR. Balakrishnan N, Vidakovic B. Encyclopedia of Statistical Sciences 2nd edition. Wiley; 2005 [cited 2020 Apr 30]. Available from: https://books.google.co.il/books?id=JX0IMQAACAAJ

14 Early JS. Management of the Charcot Ankle. In: Herscovici JD, editor. The Surgical Management of the Diabetic Foot and Ankle. Switzerland: Springer International Publishing; 2016. p. 143–54.

15 Simon SR, Tejwani SG, Wilson DL, Santner TJ, Denniston NL. Arthrodesis as an early alternative to nonoperative management of charcot arthropathy of the diabetic foot. J Bone Joint Surg Am 2000; 82-A:939–50. doi: 10.2106/00004623-200007000-00005

16 Lee BH, Fang C, Kunnasegaran R, Thevendran G. Tibiotalocalcaneal arthrodesis with the hindfoot arthrodesis nail: a prospective consecutive series from a single institution. J Foot Ankle Surg 2018; 57:23–30. doi: 10.1053/j.jfas.2017.05.041

17 Goebel M, Gerdesmeyer L, Mückley T, Schmitt-Sody M, Diehl P, Stienstra J, Bühren V. Retrograde intramedullary nailing in tibiotalocalcaneal arthrodesis: a short-term, prospective study. J Foot Ankle Surg 2006; 45:98–106. doi: 10.1053/j.jfas.2005.12.001

18 Pinzur MS, Kelikian A. Charcot ankle fusion with a retrograde locked intramedullary nail. Foot Ankle Int 1997; 18:699–704. doi: 10.1177/107110079701801104.

19 Hammett R, Hepple S, Forster B, Winson I. Tibiotalocalcaneal (hindfoot) arthrodesis by retrograde intramedullary nailing using a curved locking nail. The results of 52 procedures. Foot Ankle Int 2005; 26:810–5. doi: 10.1177/107110070502601004

20 Chraim M, Krenn S, Alrabai HM, Trnka HJ, Bock P. Mid-term follow-up of patients with hindfoot art hrodesis with retrograde compression intramedullary nail in Charcot neuroarthropathy of the hindfoot. Bone Joint J 2018; 100-B:190–196. doi: 10.1302/0301-620X.100B2.BJJ-2017-0374.R2

21 Siebachmeyer M, Boddu K, Bilal A, Hester TW, Hardwick T, Fox TP, Edmonds M, Kavarthapu V. Outcome of one-stage correction of deformities of the ankle and hindfoot and fusion in Charcot neuroarthropathy using a retrograde intramedullary hindfoot arthrodesis nail. Bone Joint J 2015; 97-B:76–82. doi: 10.1302/0301-620X.97B1.34542

22 Lucas Y Hernandez J, Abad J, Remy S, Darcel V, Chauveaux D, Laffenetre O. Tibiotalocalcaneal arthrodesis using a straight intramedullary nail. Foot Ankle Int 2015; 36:539-46. doi: 10.1177/1071100714565900

23 Brodsky JW, Verschae G, Tenenbaum S. Surgical correction of severe deformity of the ankle and hindfoot by arthrodesis using a compressing retrograde intramedullary nail. Foot Ankle Int 2014; 35:360–7. doi: 10.1177/1071100714523270

24 Elgohary HAS, Elghaffar MA. Intramedullary nail for Tibiotalocalcaneal Arthrodesis in charcot hindfoot and its implication on quality of life in egyptian patients. Foot Ankle Stud 2018; 2:1009.

25 Emara KM, Ahmed Diab R, Amr Hemida M. Tibio-calcaneal fusion by retrograde intramedullary nailing in charcot neuroarthropathy. Foot 2018; 34:6–10. doi: 10.1016/j.foot.2017.11.003

26 Caixeta TB, Júnior MO, de Castro RV, Martins JS, Costa EN, Albieri AD, de Moraes FB. Tibiotalocalcaneal arthrodesis with retrograde intramedullary nailing: 29 patients' clinical and functional evaluation. Rev Bras Ortop 2014; 49:56–61. doi: 10.1016/j.rboe.2013.12.017

27 Niinimäki TT, Klemola TM, Leppilahti JI. Tibiotalocalcaneal arthrodesis with a compressive retrograde intramedullary nail: a report of 34 consecutive patients. Foot Ankle Int 2007; 28:431–4. doi: 10.3113/FAI.2007.0431

28 Mendicino RW, Catanzariti AR, Saltrick KR, Dombek MF, Tullis BL, Statler TK, Johnson BM. Tibiotalocalcaneal arthrodesis with retrograde intramedullary nailing. J Foot Ankle Surg 2004; 43:82–6. doi: 10.1053/j.jfas.2004.01.012

29 Ettinger S, Plaass C, Claassen L, Stukenborg-Colsman C, Yao D, Daniilidis K. Surgical management of charcot deformity for the foot and ankle-radiologic outcome after internal/external fixation. J Foot Ankle Surg 2016; 55:522–8. doi: 10.1053/j.jfas.2015.12.008

30 Lee M, Choi WJ, Han SH, Jang J, Lee JW. Uncontrolled diabetes as a potential risk factor in tibiotalocalcaneal fusion using a retrograde intramedullary nail. Foot Ankle Surg 2018; 24:542–548. doi: 10.1016/j.fas.2017.07.006

31 Caravaggi CM, Sganzaroli AB, Galenda P, Balaudo M, Gherardi P, Simonetti D, *et al*. Long-term follow-up of tibiocalcaneal arthrodesis in diabetic patients with early chronic Charcot osteoarthropathy. J Foot Ankle Surg 2012; 51:408–11. doi: 10.1053/j.jfas.2012.04.007