



Outcomes of Hindfoot and Ankle Arthrodesis in Patients with Charcot Neuroarthropathy

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Abstract

Background. Involvement of the hindfoot and ankle in diabetic Charcot neuroarthropathy is often associated with subtotal or total defects of the talus, leading to unstable multiplanar deformities and a significant loss of weight-bearing capacity in the affected limb. Numerous arthrodesis techniques and fixation methods have been developed; however, in most cases, the final choice of surgical treatment depends on the surgeon's preference.

The aim of the study – to evaluate the outcomes of the surgical treatment of patients with hindfoot and ankle deformities due to Charcot neuroarthropathy who underwent arthrodesis using various fixation methods.

Methods. A retrospective analysis was conducted on 96 patients (97 feet) with Charcot neuroarthropathy affecting the hindfoot. Of these, 28 patients had type 1 diabetes, and 53 had type 2 diabetes. The average follow-up period was 21.0 ± 1.0 months. Arthrodesis with the Ilizarov external fixator was performed in 86 (88.7%) cases, and internal fixation using screws, plates, or intramedullary nails was used in 11 (11.3%) cases.

Results. Bony ankylosis and fusion were achieved in 95 (98.0%) cases, including 85 (98.8%) out of 86 cases with external fixation and 10 (90.9%) out of 11 cases with internal fixation. Due to noncompliance with weight-bearing protocols, revision arthrodesis was required in 9 (9.3%) cases at different stages of treatment and rehabilitation. Septic complications occurred in 20 (20.6%) cases at various treatment stages.

Conclusions. High rates of bony ankylosis formation were achieved with both external and internal fixation methods. However, external fixation proved to be a more reliable treatment option for patients with Charcot neuroarthropathy, given the typical characteristics of this cohort of patients, including poor skin condition, high BMI, reduced compliance, and challenges in adhering to fixation and weight-bearing regimens.

Keywords: Charcot neuroarthropathy, hindfoot arthrodesis, ankle arthrodesis, bone defect reconstruction, bone grafting.

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Результаты выполнения артродеза заднего отдела стопы и голеностопного сустава у пациентов с нейроостеоартропатией Шарко

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Реферат

Актуальность. Поражение заднего отдела стопы и голеностопного сустава при диабетической нейроостеоартропатии Шарко нередко сопровождается формированием субтотальных и тотальных дефектов таранной кости, что приводит к развитию нестабильных многоплоскостных деформаций, а также резкому нарушению опороспособности конечности. На сегодняшний день разработано множество различных техник выполнения артродеза и способов фиксации, однако в большинстве случаев окончательное решение о применении того или иного метода зависит от предпочтений хирурга.

Цель исследования — оценить результаты оперативного лечения пациентов с деформациями заднего отдела стопы и голеностопного сустава при нейроостеоартропатии Шарко, которым был выполнен артродез пораженных суставов с фиксацией различными способами.

Материал и методы. Проведен анализ результатов лечения 96 пациентов (97 стоп) с нейроостеоартропатией Шарко, сопровождающейся поражением заднего отдела стопы, из них с сахарным диабетом 1-го типа — 28 пациентов; 2-го типа — 53 пациента. Средний срок наблюдения после операции составил $21,0 \pm 1,0$ мес. Артродез с применением чрескостного остеосинтеза аппаратом Илизарова выполняли в 86 (88,7%) случаях; фиксацию погружными конструкциями (винтами, скобами, интрамедулярным штифтом) — в 11 (11,3%).

Результаты. Формирование костного анкилоза и сращение достигнуто в 95 (98,0%) случаях, из них после артродеза методом чрескостного остеосинтеза в 85 (98,8%) из 86 случаев, а при выполнении артродеза внутренними фиксаторами — в 10 (90,9%) из 11 случаев. В связи с нарушением режима разгрузки оперированной конечности выполнение повторного артродеза потребовалось в 9 случаях (9,3%) на различных этапах проводимого лечения и реабилитации. В 20 (20,6%) случаях произошли гнойные осложнения на различных сроках и этапах проводимого лечения.

Заключение. Высокие показатели формирования костного анкилоза достигнуты как при выполнении артродеза методом чрескостного остеосинтеза, так и после использования внутренних фиксаторов. Метод чрескостного остеосинтеза является более надежным способом лечения пациентов с нейроостеоартропатией Шарко с учетом особенностей данной когорты пациентов: плохого состояния кожных покровов, высокого ИМТ, снижения комплаентности пациентов и адекватности соблюдения ими предписанных режимов фиксации и разгрузки конечности.

Ключевые слова: нейроостеоартропатия Шарко, артродез заднего отдела стопы, артродез голеностопного сустава, замещение костных дефектов, костная пластика.

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INTRODUCTION

Charcot neuroarthropathy is characterized by progressive bone destruction in the context of neuropathy of various origins (such as *diabetes mellitus*, syphilis, *spina bifida*, etc.). Currently, the most common cause is *diabetes mellitus*, which leads to impaired weight-bearing function of the limb and is often associated with septic and necrotic complications [1, 2]. In diabetic Charcot neuroarthropathy (DCN), the hindfoot is affected in up to 10% of cases, with the midfoot – particularly the Lisfranc joint – being most frequently involved, resulting in the typical rocker bottom foot deformity seen in this condition [3]. However, hindfoot involvement with irreversible bone destruction presents a much more severe clinical course. The instability and multiplanar nature of the deformity in this area are often associated with subtotal or total defects of the talus, which significantly compromise the weight-bearing function of the limb, as this region initially bears the entire body weight before transmitting it to the forefoot [4]. According to the recommendations of the International Working Group on the Diabetic Foot (2023), primary arthrodesis is indicated in cases of DCN involving the hindfoot and ankle joint [5].

To stabilize the hindfoot and ankle joint in deformities caused by DCN, arthrodesis of one or more affected joints is performed [6, 7]. Proponents of external fixation emphasize the many advantages of this method in the treatment of patients with Charcot neuroarthropathy [8, 9, 10, 11, 12]. Others prefer internal fixation techniques, particularly using locking intramedullary nails, to stabilize the fusion [13, 14, 15, 16, 17].

There are many different classification systems for describing diabetic Charcot neuroarthropathy, though none individually provide a complete clinical picture. For localizing the pathological process, the most widely used is the anatomical classification by L. Sanders and R. Frykberg [18]. To assess the depth and extent of the condition in the presence of ulcerations, the F.W. Wagner Jr. [19] and WIFL [20] classifications have been developed, with the latter also taking into account the degree of ischemia. The pathophysiological classification by S.N. Eichenholtz [21] based

on radiographic findings, and the MRI-based classification by E.A. Chantelau and G. Grützner [22] are used to determine the stage of DCN.

Reconstructive surgery is one of the most promising treatment options, as it can halt the progression of the disease, restore the limb's weight-bearing function, and help avoid amputation [23, 24]. The literature presents conflicting information regarding the optimal method of fixation in DCN patients with hindfoot and ankle involvement. Numerous surgical techniques and fixation methods for arthrodesis have been developed; however, in most cases, the final choice depends on the surgeon's individual preference [25, 26].

The aim of the study – to evaluate the outcomes of the surgical treatment of patients with hindfoot and ankle deformities due to Charcot neuroarthropathy who underwent arthrodesis using various fixation methods.

METHODS

An analysis was conducted on the treatment outcomes of 96 patients (97 feet) with Charcot neuroarthropathy involving the hindfoot, including 37 men and 59 women. The patients received treatment at the Center for Foot and Diabetic Foot Surgery of the Yudin City Clinical Hospital and Branch No. 1 of Demikhov City Clinical Hospital (formerly City Clinical Hospital No. 13) from 2020 to 2024. The median age of the patients was 52 years [44-61] (min – 21, max – 79). The median body mass index (BMI) was 29 kg/m² [25-35] (min – 17, max – 46). The characteristics of the study group are presented in Table 1.

Table 1
Characteristics of patients with Charcot neuroarthropathy

Parameter	Number of patients	%
Type 1 <i>diabetes mellitus</i>	28	29.2
Type 2 <i>diabetes mellitus</i>	53	55.2
No <i>diabetes mellitus</i>	15	15.6
Mean age, years	52.0±1.3	
Mean BMI, kg/m ²	30.0±0.7	

In 33 (34.0%) cases, there was combined involvement of the hindfoot and midfoot. In 11 (11.3%) cases, patients had previously undergone surgical treatment of the hindfoot (arthrodesis using various techniques) at their local healthcare facilities for foot deformities associated with Charcot neuroarthropathy.

To describe the localization of the pathological process in the hindfoot, we used the anatomical classification by L. Sanders and R. Frykberg. To describe the depth and extent of ulcerative lesions, we applied the classification by F.W. Wagner Jr. The staging of the pathological process was assessed according to the classification by S.N. Eichenholtz. The characteristics of hindfoot and ankle involvement in the patient cohort are presented in Table 2.

Table 2
Characteristics of hindfoot and ankle joint lesions

Classification	Stage	Number of feet (n = 97)	
		n	%
Sanders and Frykberg	IV	74	76.3
	IV-V	16	16.5
	V	7	7.2
Wagner	0	66	68.0
	1	3	3.1
	2	19	19.6
	3	9	9.3
Eichenholtz	1	5	5.2
	2	58	59.8
	3	34	35.0



Figure 1. X-rays of the ankle in a patient with Charcot neuroarthropathy

Indications for orthopedic reconstruction were determined based on the physical examination and radiographic assessment of the affected limb segment. Reconstruction was performed to restore the weight-bearing function of the limb, halt disease progression, and prevent amputation. An example of ankle joint involvement in Charcot neuroarthropathy is shown in Figure 1.

The choice of arthrodesis technique and fixation method was based on the following factors:

- patient's compliance, living conditions, and availability or absence of external assistance;
- presence or absence of an acute septic process with bone involvement, requiring a two-stage arthrodesis;
- condition of the skin and presence or absence of ulcerative lesions at the intended surgical site;
- stage of the pathological process in accordance with the Eichenholtz pathophysiological classification.

In this case series, preference for fixation following arthrodesis was given to the Ilizarov external fixator, considering its ability to provide continuous compression at the fusion site throughout the whole treatment period. In cases requiring closure of soft tissue defects resulting from debridement of ulcers or septic wounds, skin flaps were used, which was necessary in 7 (7.2%) cases. Arthrodesis using the Ilizarov external fixator was performed in 86 (88.7%) cases, while internal fixation with screws, plates, or intramedullary nails was used in 11 (11.3%) cases. Examples of surgical interventions are shown in Figure 2.

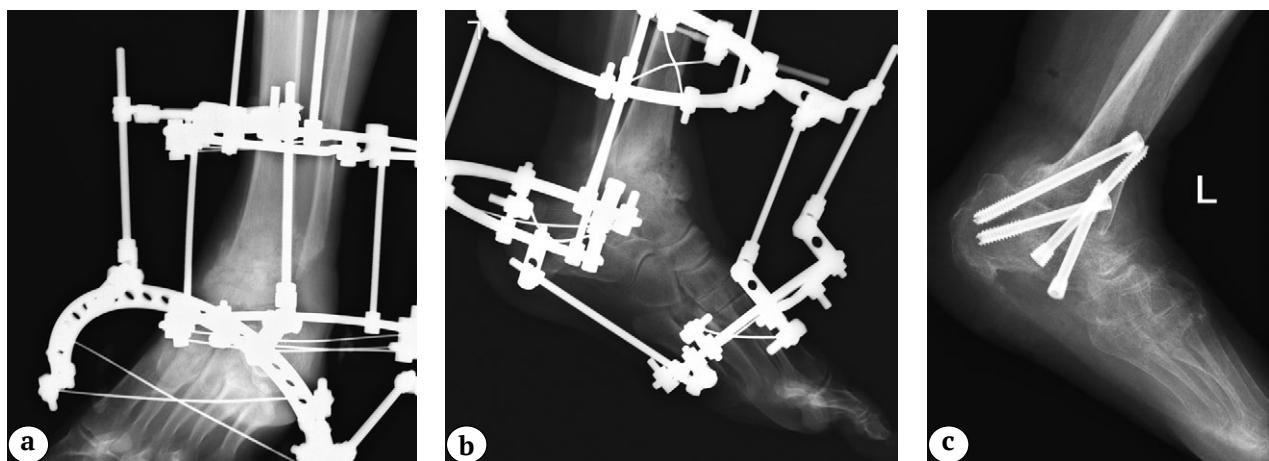


Figure 2. X-rays after ankle arthrodesis using external fixation in the AP (a) and lateral (b) views; tibiocalcaneal arthrodesis with internal fixation in the lateral view (c)

All patients underwent preoperative ultrasound examination of the arteries and veins of the lower limbs to rule out thrombosis or hemodynamically significant vascular impairment.

During operation, affected bone fragments were excised, articular surfaces were resected, and synovectomy was performed. In the presence of large bone defects, arthrodesis was performed using auto- and/or allogeneic bone grafting material, which was required in 44 (45.4%) cases.

In 7 (7.2%) cases with active septic infection, debridement of affected bones and surrounding tissues was performed, followed by the placement of an antibiotic cement spacer to fill the resulting bone defect, with subsequent external fixation using the Ilizarov apparatus. After resolution of the septic and inflammatory process, the spacer was removed, arthrodesis was performed, and the external fixator was reassembled.

The median follow-up period after operation was 21 months [14-28] (min – 3, max – 46), and the average follow-up duration was 21.0 ± 1.0 months. This study assessed the presence or absence of fusion, restoration of the limb's weight-bearing capacity, arrest of the pathological process, frequency and causes of septic complications, and overall mortality in the patient group.

Postoperative period

In the postoperative period, all patients ambulated using additional support (crutches, walkers, or knee crutches) without weight-bearing on the operated limb. Stepwise radiographic and MSCT evaluations of the hindfoot were performed, along

with glycemic control and antibiotic therapy based on culture results. Upon radiological signs of union and successful clinical testing, the Ilizarov apparatus was removed, followed by stabilization with a posterior plaster splint until the wounds at the pin sites had healed.

After 2-3 weeks, the posterior plaster splint was replaced with a total contact cast (TCC), and gradual ambulation with additional support in the TCC was initiated, with progressive loading of the operated limb. Monthly radiographic monitoring of the operated segment was performed. Walking in custom-made orthopedic footwear was allowed once full weight-bearing on the foot without additional support was achieved.

Statistical analysis

Data collection, correction, and systematization, as well as obtained results' visualization, were carried out using Microsoft Office Excel 2021 spreadsheets. Using the descriptive statistics tool in Microsoft Excel, the median (Me) with interquartile range [$Q_1 - Q_3$], as well as minimum and maximum values and the arithmetic mean with standard error ($M \pm SE$), were calculated for age, BMI, and postoperative follow-up duration. Relative values were expressed as percentages.

RESULTS

In all patients included in this study, ultrasound examination revealed changes in the walls of the lower limb arteries in the form of thickening and increased echogenicity. In 95 (97.9%) cases, there were hemodynamically insignificant blood flow disturbances, manifested as mild arterial

stenosis with preserved main or altered-main blood flow. In 2 (2.1%) patients with *diabetes mellitus*, hemodynamically significant blood flow disturbances were identified in several lower limb arteries: pronounced stenosis with a marked decrease of blood flow, up to complete occlusion. Therefore, these patients underwent CT angiography with bolus contrast enhancement of the vessels, followed by transluminal balloon angioplasty and recanalization of the affected arteries. The advanced examinations of the degree of ischemia, such as segmental pressure measurement or transcutaneous oxygen tension measurement, were not performed in this study.

Surgical interventions in the hindfoot region were performed on 97 feet – one patient underwent staged operations on both feet. In 7 (7.2%) cases, isolated involvement of the calcaneus was identified (type V according to the Sanders and Frykberg classification). Of these, in 6 (6.2%) cases, corrective osteotomy with subtalar arthrodesis was performed: internal fixation in 5 (5.2%) cases, and in one (1.0%) case, in a patient with active stage 1 pathological process according to the Eichenholtz classification, fixation was achieved using the Ilizarov external fixator. In one (1.0%) case, with isolated localization of the pathological process in the area of the calcaneal tuberosity, a corrective calcaneal osteotomy with Achilles tendon reinsertion was performed (Table 3).

Bony ankylosis and fusion were achieved in 95 (98.0%) cases, a weight-bearing neoarthrosis in 1 (1.0%) case, and a weight-bearing fibrous ankylosis also in 1 (1.0%) case. Specifically, in cases where arthrodesis was performed using

internal fixation, bony ankylosis and fusion were achieved in 10 (90.9%) out of 11 cases, while in cases with external transosseous osteosynthesis, this outcome was achieved in 85 (98.8%) out of 86 cases. Due to noncompliance with the weight-bearing regimen, revision arthrodesis was required in 9 (9.3%) cases at various stages of treatment and rehabilitation.

The outcomes of treatment following arthrodesis using internal fixation and transosseous osteosynthesis are presented in Table 4.

Complications

In patients who underwent arthrodesis with internal fixation, peri-implant infection was observed in 2 (18.2%) cases: at 2.5 weeks and 2.5 months postoperatively. In the first case, removal of the hardware was required, followed by the placement of antibiotic cement beads and, at the second stage (after 2 months), resection arthrodesis using the Ilizarov external fixator with bone defect reconstruction using a bone autograft. In the second case, a long-lasting non-healing postoperative wound was noted. After the removal of one staple, signs of acute inflammation were resolved.

In one (1.2%) case, a week after arthrodesis performed using the Ilizarov apparatus, signs of pin track infection and postoperative wound infection developed, which required replacement of the compromised wires, surgical wound debridement, and placement of an antibiotic cement spacer. After resolution of the acute inflammation, the cement spacer was removed 2.5 months later, and revision arthrodesis was performed.

Surgical interventions performed on the hindfoot

Surgical intervention	Number of feet (n = 97)	
	Absolute count	%
Ankle joint arthrodesis	22	22.7
Ankle and subtalar joint arthrodesis	12	12.4
Panarthrodesis	33	34.0
Tibiocalcaneal arthrodesis	13	13.4
Two-stage arthrodesis with cement spacer	9	9.3
Corrective osteotomy of the calcaneus with subtalar joint arthrodesis	6	6.2
Corrective osteotomy of the calcaneus with the Achilles tendon reinsertion	1	1.0

Table 3

Characteristics of treatment outcomes in patients undergoing arthrodesis*Table 4*

Parameter	Number of cases	%
<i>Arthrodesis with internal fixators</i>		
Total	11	100% (11.3% of the total number)
Bony ankylosis	10	90.9%
Fibrous ankylosis	1	9.1%
<i>Arthrodesis using external fixation</i>		
Total	86	100% (88.7% of the total number)
Bony ankylosis	85	98.8%
Weight-bearing neoarthrosis	1	1.2%

In 8 (9.3%) cases, due to patients' non-compliance with the weight-bearing regimen, signs of pin track infection were observed within 5 months after arthrodesis. In 7 of these cases, replacement of the wires was required. In one case, the external fixator was removed, and the arthrodesis was stabilized with crossing wires and immobilized using a plaster splint.

Due to noncompliance with the weight-bearing regimen and improper care of the external fixator, abscess drainage was required in 3 (3.5%) cases at 2 to 3.5 months after arthrodesis using the Ilizarov apparatus. In another 3 cases (3.5%), improperly fitted orthoses led to the development of pressure sores. In 2 of these cases, occurring at 1 and 2.5 months after Ilizarov external fixator removal, abscesses developed due to the secondary infection, requiring surgical drainage. In one case, conservative treatment was sufficient and consisted of regular dressing changes. In 3 (3.5%) cases, abscesses formed between 2 and 5.5 months after external fixator removal due to inadequate postoperative wound care and non-adherence to weight-bearing restrictions. These complications required surgical debridement of the wound and abscess drainage. In total, septic complications following arthrodesis with transosseous osteosynthesis occurred in 18 (20.9%) cases at various time points and treatment stages.

The characteristics of complication types following arthrodesis with transosseous osteosynthesis at various treatment stages are presented in Table 5.

During 4 years of patient follow-up, there were 9 (9.3%) fatal cases. Two (2.1%) patients

died from cardiovascular diseases (stroke, heart attack, acute heart failure), and 4 (4.1%) patients died from lung diseases (pneumonia, pulmonary edema). One (1.0%) patient died 1.5 years after surgery due to the progression of chronic venous insufficiency and the formation of multiple infected trophic ulcers on both lower legs and feet, which led to the generalization of the infectious process, development of multiple organ failure, septic shock, and pulmonary embolism, resulting in death. One (1.0%) patient died 1.5 years postoperatively due to the progression of chronic cerebral ischemia and widespread pressure sores formation, which led to terminal cerebral and pulmonary edema. One (1.0%) patient died 2.5 months after the start of weight-bearing on the operated limb due to the development of sepsis and multiple organ failure as a complication of foot phlegmon and multiple abdominal and retroperitoneal abscesses.

DISCUSSION

The choice of the optimal surgical treatment method and arthrodesis fixation technique remains a subject of debate. The surgical intervention itself in this patient cohort is associated with numerous risks, including postoperative septic complications, thrombosis due to prolonged immobilization, recurrence of deformity or failure of the performed arthrodesis, and, consequently, the need for revision surgery.

In 2022, M.Y. Bajuri et al. conducted a meta-analysis that reviewed published data on the treatment outcomes of patients with Charcot neuroarthropathy [27]. The average fusion rate following arthrodesis of the hindfoot and ankle

Table 5

Causes of septic complications and methods of treatment in the postoperative period after arthrodesis using external fixation

Cause		Methods of managing	Number of cases (n = 18)	%*
During fixation with the Ilizarov apparatus	Pin track infection	Removal of the Ilizarov apparatus, fixation with crossing wires Reassembly of the Ilizarov apparatus	1 8	1.2 9.3
	Foot or ankle joint abscess / phlegmon	Abscess drainage	3	3.5
After removal of the Ilizarov apparatus	Development of pressure sore / abscess due to improper orthosis use	Abscess drainage Conservative treatment: dressing changes	2 1	2.3 1.2
	Development of abscess due to noncompliance with postoperative wound care and weight-bearing protocol	Surgical wound debridement, abscess drainage	3	3.5

* The percentage is based on the number of patients who underwent arthrodesis via external fixation.

using a retrograde intramedullary nail was 83.1%, while with the use of the Ilizarov apparatus it was 78%. The amputation rate among patients who underwent arthrodesis with internal fixation was 7.17%, compared to 9.7% for those treated with circular external fixator. The authors concluded that arthrodesis with retrograde intramedullary nailing is the preferred method of reconstruction in the absence of ulcers.

In contrast, B. El-Alfy et al., in their assessment of treatment outcomes in 27 patients with Charcot neuroarthropathy of the ankle joint, reported a higher rate of successful arthrodesis using the Ilizarov external fixator: 86% compared to 77% in patients treated with intramedullary nail. However, the authors also noted that pin track infection occurred in more than half of the cases [28].

In our study, bony ankylosis was achieved in 98.0% of cases: in 85 (98.8%) cases following arthrodesis using the external fixation, and in 10 (90.9%) cases after arthrodesis with internal fixation. These results exceed the previously reported outcomes in international studies for both techniques. However, in our study, the group of patients who underwent arthrodesis with internal fixation was relatively small. Therefore, further research involving a larger number of patients is needed for a more objective assessment. No amputations were performed in

the study group during the follow-up period, which also surpasses the results reported in international sources [27, 28].

Septic complications occurred in 20 (20.6%) cases: in 20.9% of patients who underwent arthrodesis using the external fixation method and in 18.2% of those managed with internal fixation. These figures, when compared to data reported in the literature, are still considered satisfactory [27, 28]. Furthermore, in our study, 85.0% of septic complications in patients treated with transosseous osteosynthesis were associated with noncompliance with external fixation care protocols, weight-bearing regimens, and/or the use of inappropriate orthoses, casts, or footwear. This once again highlights the critical importance of patient adherence to treatment, preserved cognitive function, and the ability to follow prescribed fixation and weight-bearing protocols, followed by gradual mobilization and rehabilitation.

At the same time, several authors have reported favorable outcomes with the use of hybrid fixation [29]. This technique may be recommended for reconstruction of the hindfoot and ankle joint in the presence of ulcerative defects and complex deformities, as it provides a higher limb salvage rate (up to 100% of cases) while causing less soft tissue trauma.

Study limitations

A limitation of this retrospective study is the unequal distribution of patients across groups depending on the arthrodesis technique used, which prevents direct comparison due to the significant difference in group sizes. Nevertheless, the overall sample size and average follow-up duration are sufficiently large, considering the relative rarity of this pathology in the hindfoot and ankle area.

Further studies are needed to evaluate the outcomes of different types of arthrodesis for hindfoot and ankle deformities in Charcot neuroarthropathy. This will also contribute to the development of algorithms for selecting appropriate techniques and fixation methods, thereby helping to define more precise treatment guidelines for patients with this condition.

CONCLUSIONS

This study demonstrated high rates of bony ankylosis formation both in cases where arthrodesis was performed using the external fixation method and when internal fixation was used. The external fixation technique proves to be a reliable treatment option for patients with Charcot neuroarthropathy, taking into account the specific characteristics of this patient cohort: poor skin condition, high BMI, reduced patient compliance, and limited adherence to prescribed fixation and weight-bearing protocols.

DISCLAIMERS

Author contribution

All authors made equal contributions to the study and the publication.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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REFERENCES

1. Rogers L.C., Frykberg R.G., Armstrong D.G., Boulton A.J., Edmonds M., Van G.H. et al. The Charcot foot in diabetes. *Diabetes Care*. 2011;34(9):2123-2129. doi: 10.2337/dc11-0844.
2. Dayton P., Feilmeier M., Thompson M., Whitehouse P., Reimer R.A. Comparison of Complications for Internal and External Fixation for Charcot Reconstruction: A Systematic Review. *J Foot Ankle Surg*. 2015;54(6):1072-1075. doi: 10.1053/j.jfas.2015.06.003.
3. Sanders L.J., Frykberg R.G. The Charcot foot. In: Bowker J.H., Pfeifer M.A. (eds.) *Levin and O'Neal's The Diabetic Foot*. 7th ed. Mosby; 2008. p. 257-283.
4. Pinzur M.S. Treatment of Ankle and Hindfoot Charcot Arthropathy. *Foot Ankle Clin*. 2020;25(2):293-303. doi: 10.1016/j.fcl.2020.02.010.
5. Schaper N.C., van Netten J.J., Apelqvist J., Bus S.A., Fitridge R., Game F. et al. IWGDF Guidelines on the prevention and management of diabetes-related foot disease. 2023. Available from: <https://wgdfguidelines.org/wp-content/uploads/2023/07/IWGDF-Guidelines-2023.pdf>.
6. Burns P.R., Dunse A. Tibiotalocalcaneal Arthrodesis for Foot and Ankle Deformities. *Clin Podiatr Med Surg*. 2017;34(3):357-380. doi: 10.1016/j.cpm.2017.02.007.
7. Ettinger S., Stukenborg-Colsman C., Plaass C., Yao D., Claassen L., Berger S. et al. Tibiocalcaneal arthrodesis as a limb salvage procedure for complex hindfoot deformities. *Arch Orthop Trauma Surg*. 2016;136(4):457-462. doi: 10.1007/s00402-016-2420-1.
8. LaPorta G.A., Begum M., Guzelak S., D'Andelet A. The Use of Hexapod External Fixation in the Management of Charcot Foot and Ankle Deformities. *Clin Podiatr Med Surg*. 2022;39(4):629-642. doi: 10.1016/j.cpm.2022.05.010.
9. Hutchinson B. Circular Fixation in Charcot. *Clin Podiatr Med Surg*. 2022;39(4):643-658. doi: 10.1016/j.cpm.2022.05.008.
10. Richman J., Cota A., Weinfeld S. Intramedullary Nailing and External Ring Fixation for Tibiotalocalcaneal Arthrodesis in Charcot Arthropathy. *Foot Ankle Int*. 2017;38(2):149-152. doi: 10.1177/1071100716671884.
11. Fabrin J., Larsen K., Holstein P.E. Arthrodesis with external fixation in the unstable or misaligned Charcot ankle in patients with diabetes mellitus. *Int J Low Extrem Wounds*. 2007;6(2):102-107. doi: 10.1177/1534734607302379.
12. Wukich D.K., Belczyk R.J., Burns P.R., Frykberg R.G. Complications encountered with circular ring fixation in persons with diabetes mellitus. *Foot Ankle Int*. 2008;29(10):994-1000. doi: 10.3113/FAI.2008.0994.
13. Bajuri M.Y., Manas A.M., Zamri K.S. Functional outcomes of tibiotalocalcaneal arthrodesis using a hindfoot arthrodesis nail in treating Charcot's arthropathy deformity. *Front Surg*. 2023;9:862133. doi: 10.3389/fsurg.2022.862133.
14. Franceschi F., Franceschetti E., Torre G., Papalia R., Samuelsson K., Karlsson J. et al. Tibiotalocalcaneal arthrodesis using an intramedullary nail: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(4):1316-1325. doi: 10.1007/s00167-015-3548-1.

15. von Recum J. Tibiotalocalcaneal corrective arthrodesis in Charcot arthropathy of the ankle with a retrograde nail. *Oper Orthop Traumatol.* 2015;27(2):114-128. (In German). doi: 10.1007/s00064-014-0336-x.
16. Rana B., Patel S. Results of Ankle and Hind foot arthrodesis in Diabetic Charcot Neuroarthropathy — A retrospective analysis of 44 patients. *J Clin Orthop Trauma.* 2021;23:101637. doi: 10.1016/j.jcot.2021.101637.
17. Cianni L., Bocchi M.B., Vitiello R., Greco T., De Marco D., Masci G. et al. Arthrodesis in the Charcot foot: a systematic review. *Orthop Rev (Pavia).* 2020;12(Suppl 1):8670. doi: 10.4081/or.2020.8670.
18. Sanders L., Frykberg R. Diabetic neuropathic osteoarthropathy: The Charcot foot. In: Frykberg R.G. (eds.) *The high risk foot in diabetes mellitus.* Edinburgh: Churchill Livingston; 1991. p. 325-333.
19. Wagner F.W. Jr. The dysvascular foot: a system for diagnosis and treatment. *Foot Ankle.* 1981;2(2):64-122. doi: 10.1177/107110078100200202.
20. Hicks C.W., Canner J.K., Karagozlu H., Mathioudakis N., Sherman R.L., Black J.H. 3rd et al. The Society for Vascular Surgery Wound, Ischemia, and foot Infection (WFNI) classification system correlates with cost of care for diabetic foot ulcers treated in a multidisciplinary setting. *J Vasc Surg.* 2018;67(5):1455-1462. doi: 10.1016/j.jvs.2017.08.090.
21. Eichenholtz S.N. Charcot joints. Springfield: Charles C. Thomas; 1966.
22. Chantelau E.A., Grützner G. Is the Eichenholtz classification still valid for the diabetic Charcot foot? *Swiss Med Wkly.* 2014;144:w13948. doi: 10.4414/smw.2014.13948.
23. Hartig N., Krenn S., Trnka H.J. Surgical treatment of the Charcot foot: long-term results and systematic review. *Orthopade.* 2015;44(1):14-24. (In German). doi: 10.1007/s00132-014-3058-8.
24. Bensman V.M., Savchenko Yu.P., Gumennyuk S.E., Triandafilov K.G., Vasil'chenko P.P., Pyatakov S.N. et al. Surgical treatment of diabetic neuroosteoarthropathy (DNOAP) and its long-term results. *Pirogov Russian Journal of Surgery.* 2017;(6):41-50. (In Russian). doi: 10.17116/hirurgia2017641-50.
25. Stapleton J.J., Zgonis T. Surgical reconstruction of the diabetic Charcot foot: internal, external or combined fixation? *Clin Podiatr Med Surg.* 2012;29(3):425-433. doi: 10.1016/j.cpm.2012.04.003.
26. Wukich D.K., Liu G.T., Johnson M.J., Van Pelt M.D., Raspovic K.M., Lalli T. et al. A Systematic Review of Intramedullary Fixation in Midfoot Charcot Neuroarthropathy. *J Foot Ankle Surg.* 2022;61(6):1334-1340. doi: 10.1053/j.jfas.2022.04.009.
27. Bajuri M.Y., Ong S.L., Das S., Mohamed I.N. Charcot Neuroarthropathy: Current Surgical Management and Update. A Systematic Review. *Front Surg.* 2022;9:820826. doi: 10.3389/fsurg.2022.820826.
28. ElAlfy B., Ali A.M., Fawzy S.I. Ilizarov External Fixator Versus Retrograde Intramedullary Nailing for Ankle Joint Arthrodesis in Diabetic Charcot Neuroarthropathy. *J Foot Ankle Surg.* 2017;56(2):309-313. doi: 10.1053/j.jfas.2016.10.014.
29. El-Mowafi H., Abulsaad M., Kandil Y., El-Hawary A., Ali S. Hybrid Fixation for Ankle Fusion in Diabetic Charcot Arthropathy. *Foot Ankle Int.* 2018;39(1):93-98. doi: 10.1177/1071100717735074.

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