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Comparison of Arthrodesis with Total Contact Casting for Midfoot Ulcerations Associated with Charcot Neuroarthropathy

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ABCDEF 1 **Yan Wang**
ABC 1 **Junlin Zhou**
BC 2 **Fen Yan**
CD 2 **Gong Li**
B 2 **Xiaofen Duan**
BF 2 **Heng Pan**
DE 2 **Jiao He**

1 Beijing Chao-Yang Hospital, Capital Medical University, Beijing, P.R. China
2 Beijing Feng-Tai Hospital, Capital Medical University, Beijing, P.R. China

Corresponding Authors: Yan Wang, e-mail: Jeryqq@sina.com; Junlin Zhou, e-mail: junlinzhou@yahoo.com
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Background: Gross deformity of the foot in Charcot neuroarthropathy can lead to foot collapse and subsequent ulceration, infection, amputation, or premature death. Total-contact casting (TCC) is a well-established treatment for neuropathic diabetic plantar foot ulcers. It was hypothesized that arthrodesis plus TCC may have advantages over TCC alone. This pilot study compared the effectiveness of arthrodesis plus TCC with TCC alone for the prevention, treatment, and recurrence of midfoot ulcerations associated with Charcot neuroarthropathy.

Material/Methods: Twenty-one subjects with plantar ulcers associated with unilateral diabetic Charcot midfoot neuroarthropathy were randomly assigned to ADS or TCC groups. The ADS group underwent an extended medial column arthrodesis procedure and TCC; ulcers were sutured directly. The TCC group underwent TCC alone with dressing changes. All patients underwent nerve conduction studies and quantitative sensory testing at baseline and during follow-up (6 and 12 months). Healing time and ulcer relapse rate were evaluated.

Result: Compared with the TCC group, there were fewer lesions in the ADS group after treatment ($P < 0.05$). Temperature testing and vibration perception threshold improved significantly after ADS ($P < 0.05$). Although the number of patients positive for pinprick and light touch sensations increased after surgery, not all patients recovered these sensations. Healing time was not significantly different between the 2 groups (24.25 ± 3.89 vs. 25.89 ± 2.84 days, $P > 0.05$). There was no ulcer recurrence after 12 months in the ADS group compared with 33.3% in the TCC group.

Conclusions: An extended medial column arthrodesis may partly improve sensory impairments and restore protective sensation in patients with Charcot neuroarthropathy.

MeSH Keywords: **Arthrodesis • Diabetic Foot • Peripheral Nervous System Diseases**

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Background

Charcot neuroarthropathy (CNA) is a debilitating condition typically affecting diabetic patients with peripheral neuropathy. This condition will develop in 1 per 600 diabetic patients and in 1 per 100 diabetic patients with neuropathy [1]. Severe foot and ankle deformity, recalcitrant ulcerations, and subsequent amputations usually result from untreated CNA [1].

CNA in diabetic patients is usually unilateral [2]. CNA lesions may affect the midfoot (60% of cases), forefoot (30%) or hind-foot and ankle (10%). Jeffcoate et al. [3] suggested that causal factors were sensory neuropathy, adequate arterial circulation, and an inflammatory response. With these factors in place, any event exacerbating an inflammation cascade characterized by hypervascularity, cytokine activity, osteoclasts and disruption of osseous and soft tissue elements will lead to typical CNA lesions. Eventually, weight bearing will cause architectural disruption of the foot [4]. Subsequent deformities of the foot, altered patterns of weight bearing and stress concentration then lead to ulcerations, recurrences, soft tissue and bony infections, amputations, and early mortality.

Although CNA is a well established complication of diabetes mellitus recognized by specialists, it is not easily diagnosed by non-specialists, particularly in its early stages [1]. Patients often see a doctor because of a refractory ulcer or recurrent ulceration in the plantar area. Unfortunately, by that stage, the patients already have gross bone deformities.

Since neuropathic diabetic plantar foot ulcers are often found over a bony prominence, offloading to reduce pressure plays an important role in treatment. Total contact casting (TCC) is a method of offloading that is superior to a removable walking cast [5,6]. Alternative approaches to improving healing time, when a total-contact cast is unavailable or contraindicated, include placing the patient in a wedge-type shoe or walking boot, the use of flexible and rigid casting tape or felt aperture padding, or complete bed rest [6–10]. Nonetheless, despite the availability of these various alternatives, TCC remains the ‘gold standard’ treatment option [6]. Although in most cases the use of a total-contact cast can be effective for allowing a patient to walk without undergoing surgery [11,12], there are drawbacks to this conservative method of treatment. Indeed, treatment with a total-contact cast limits the ability of a patient to function on a day-to-day basis for an extended period of time.

Arthrodesis has been described as an effective method of limb salvage for patients with CNA who have severe deformity and instability, and for who a cast or brace is not a treatment option and amputation seems inevitable. Current therapeutic efforts for chronic CNA are directed at supporting the foot architecture while the self-limited inflammatory response subsides

Table 1. Inclusion and exclusion criteria.

Inclusion criteria
1. Unilateral medial column deformity (involving the talus, navicular, cuneiforms, or 1 st , 2 nd or 3 rd metatarsal) based on the location of the Charcot neuroarthropathy
2. Radiographic evidence of overt arthropathy
3. Limb-threatening ulceration associated with diabetic CNA
4. Fixed, non-reducible midfoot deformity
Exclusion criteria
1. Osteomyelitis

and bone is reconstituted. Retrospective reports and prospective series of midfoot arthrodesis in CNA have shown that this technique is usually reserved for chronic cases with irreversible deformities and/or joint instability [13] to improve foot plantar pressures and balance [14,15] and to minimize ulceration and foot amputation risk [16].

No previous studies have directly compared arthrodesis and TCC with TCC alone. In view of the utility of arthrodesis in patients with severe deformity and instability, it was hypothesized that the additional use of arthrodesis in patients that would normally be treated with TCC alone may be therapeutically beneficial in the management of chronic midfoot ulceration and the prevention of its recurrence. Therefore, the present study was performed to compare the effectiveness of arthrodesis and TCC with TCC alone for the prevention (sensory nerve function and plantar pressure), treatment and recurrence of CNA midfoot ulcerations.

Material and Methods

Patients

This was a pilot randomized prospective trial in 21 subjects (21 feet in 13 men and 8 women, average age of 64±9 years) conducted between August 2011 and December 2013. All patients were treated at the department of Orthopedic Surgery of the Beijing Feng Tai Hospital (China). The inclusion and exclusion criteria are presented in Table 1. This study was approved by the medical ethics committee of the hospital and all patients provided written informed consent.

Study design

Subjects were assigned to the arthrodesis (ADS) or TCC groups using computer-generated random tables. The ADS group

Figure 1. A 64-year old man with a diabetic Charcot foot. (A) Yellowish change in color of the tibial nerve in the tarsal tunnel. (B) The apex of the deformity was the tarsometatarsal and naviculocuneiform joints. (C) The patient underwent reconstruction of the medial column using an anterior cervical plate and limited internal screw fixation. (D) Re-establishment of structural alignment and bone fusion 12 months after surgery.

underwent an extended medial column arthrodesis procedure and TCC. The TCC group underwent TCC alone.

Arthrodesis

After induction of continuous epidural anesthesia and application of a thigh tourniquet, a curvilinear incision was made medial to the extensor hallucis longus and was made sufficiently long to expose the medial side of the foot for insertion of a plate and screws. The medial venous plexus was preserved as much as possible proximally and distally for post-operative edema management. The medial plantar nerve was identified within the incision and its thickness, position and blood supply were examined (Figure 1A, 1B). The lesion area was examined. Ligaments, articular cartilage, loose callus and fibrous tissue were excised to provide a good bed for arthrodesis. Dorsal soft tissue mobilization was minimal, but it was necessary to facilitate exostectomy, ostectomy and realignment. A linear

medial capsulotomy was performed based on the apex of the Charcot deformity and often extended from the talonavicular joint to the first tarsometatarsal joint. A linear tenotomy of the tibialis anterior tendon was sometimes performed to facilitate necessary exposure and access to the entire medial column. The dorsal and plantar tendon stumps were tagged for re-approximation on closure.

Resection of the articular surfaces of the unstable segments of the medial column was achieved using an osteotome, curettage and/or sagittal saw osteotomies when necessary. Osteotomy was performed if necessary to facilitate improved sagittal and transverse plane alignment of the medial column. Using standard AO techniques, titanium screws and plates or screws alone were inserted from the medial and dorsal directions to ensure that a stable reduction was maintained and that compression was present across as many arthrodesis sites as possible. The size and placement of the plate and screws depended on the

nature of the involved areas of the midfoot, the severity of the subluxations or dislocations, and the amount of bone fragmentation (Figure 1C, 1D). Prophylactic antibiotics were administered intravenously before the procedure and during the first 24 hours. After surgery, all patients were kept non-weight bearing in a cast for 6 to 12 weeks. Weight bearing was increased on the basis of radiographic and clinical assessment of union.

Total contact casting

With the patient lying prone, the leg was supported vertically with the knee flexed at 90° and the foot and ankle in neutral position. A roll of cotton cast (4- or 6-inch) (Webril, Kendall, Mansfield, MA, USA) was used to wrap the leg from the tibial tubercle to the forefoot. The cast roll was advanced by overlapping the previous layer by 50%, resulting in a thin layer of no more than 2 plies of cast. The plaster was carefully molded on the midfoot, hindfoot, heel, malleoli and tibial crest. During wrapping, the area of the lesion was exposed carefully. All patients were kept non-weight bearing until the plantar ulcer healed.

Treatment for the plantar ulcer

In the ADS group, debridement was performed before surgery and all ulcers were closed by direct suture after arthrodesis. In the TCC group, preparation of the ulcer for application of the cast included debridement of all necrotic tissues from the wound and paring of all calluses. The wound was covered with a sterile non-adherent dressing (Telfa, Kendall, Mansfield, MA, USA) before molding the cast. Dressings were changed once every 2 days through a window in the TCC until wound healing.

Data collection

All nerve studies were conducted at baseline (2 weeks before surgery), 6 months after surgery and 12 months after surgery. Follow-up ended at 12 months for the present study. All nerve conduction studies (NCS) and quantitative sensory testing (QST) were performed by the same physician who was blind to the study grouping.

Nerve conduction studies

Standardized techniques for NCS with controlled temperature (skin at 30°C and room at 25°C), quiet environment and fixed distal distances were used. Temperature equilibrium between body and environment was achieved using a 20-minute rest. The peroneal, tibial and sural nerves on the side affected by CNA were tested. Sensory NCS were performed antidromically. All stimulations and recordings were done using surface electrodes. Corresponding distances for sensory NCS were 130 mm for the peroneal nerve, 110 mm for the tibial nerve,

and 140 mm for the sural nerve. Measurements of distances, response latencies and amplitudes were done in a standard fashion using onset latencies and baseline-to-peak amplitudes. Measurements from the initial positive peak to negative peak were made for sensory responses.

Quantitative sensory testing

QST was based on 4 parameters. Testing was performed in a quiet indoor environment with a room temperature of 25°C and skin temperature of 30°C. Vibration perception threshold (VPT) was assessed using a 128-Hz Rydel-Seiffer tuning fork [17] at the plantar hallux. Temperature sensation, including cold perception threshold (CPT) and warm perception threshold (WPT), was measured on the lateral dorsal foot at 32°C, a temperature range of 0–50°C, and a temperature change rate of 1°C/s. Temperature sensation was measured 2 times at each point, with a time interval of 5 seconds. Pain sensation was investigated using a Pinprick test. Light touch was assessed using a 10-g Semmes-Weinstein monofilament (SWMF). The nylon filament was placed perpendicular to the plantar foot skin at 3 predetermined points. Pressure was applied until the filament buckled. The filament was held in place for approximately 1 second and then released.

Follow-up

All patients were followed up for 12 months. Orthopedic adverse reactions were assessed using physical examination and X-rays.

Statistical analysis

Continuous data are presented as mean and standard deviation, and were analyzed using independent sample t-tests. A 2×3 (group×times testing) repeated-measures multiple analysis of variance (ANOVA) was used to determine differences for each of the lower peripheral nerve performance measures. P-values <0.05 were considered significantly different. Analysis was conducted using SPSS 18 (IBM, Armonk, NY, USA).

Results

Characteristics of the patients

Table 2 presents the characteristics of the patients. Most subjects were overweight or obese. All subjects had plantar numbness, and 10 of them had plantar pain, which was typically described as a burning sensation. The preoperative ankle-brachial index of all patients was normal. Glycemic control was poor. There was no difference between the 2 groups for demographics (Table 2).

Table 2. Patient characteristics.

Variable	Arthrodesis (n=12)	Total contact cast (n=9)
Age (years)	62.8±3.6	65.0±3.8
Duration of diabetes (months)	15.3±4.5	15.9±4.0
Males (females)	7 (5)	5 (4)
BMI (kg/m ²)	33.4±4.9	30.4±5.6
HbA1c (%)	7.8±0.9	7.5±1.0
Foot ulcers (n)	11	9
Ulcers (cm ²)	5.7±1.7	5.0±1.7

Results are presented as mean ± standard deviation, or numbers. All variables were comparable between the two groups.

Ulcerations

There was no significant difference (all $P>0.05$) between the ADS and TCC groups in ulcer number, duration and dimension (Table 3). All ulcers in the ADS and TCC groups healed after treatment (24.25±3.89 vs. 25.89±2.84 days, $P=0.632$). Re-ulceration rates were significantly higher in the TCC group compared with the ADS group. At one year of follow-up, 3 of the 9 (33.3%) patients in the TCC group suffered from new ulcers, compared with none in the ADS group ($P<0.05$).

Table 3. Wound healing time according to treatment.

Variable	Arthrodesis (n=12)	Total contact cast (n=9)
Ulcer duration (days)	25.3±6.5	27.9±4.0
Ulcers (cm ²)	5.7±1.7	5.0±1.7
Healing time (days)	24.3±3.9	25.9±2.8
Recurrence rate	0%	33.3%*

* $P<0.05$ vs. the arthrodesis group.

Nerve conduction

NCS data are presented in Table 4. All NCS parameters at baseline were comparable between the 2 groups (all $P>0.05$). Group×time interactions were observed for tibial nerve and peroneal nerve conduction, indicating that ADS affected these variables over time differently than TCC.

Mean tibial nerve amplitude and latency improved after arthrodesis ($P<0.05$ baseline vs. 6 months, Table 4) and did not change further at 12 months. At 12 months, tibial nerve amplitude and latency following TCC were not improved (all $P>0.05$, Table 4). At 12 months, tibial nerve conduction after ADS was not different from baseline ($P>0.05$), but was decreased in the TCC group ($P<0.05$).

Table 4. Nerve conduction velocity according to treatment.

Variable	Group (total n)	Baseline (n of positive)	6 months (n of positive)	12 months (n of positive)	P-value for group-time interaction
Tibia nerve amplitude (μV)	Arthrodesis (12)	0.85±0.21 (8)	4.31±1.41* (12)*	5.71±1.29* (12)*	<0.05
	Total contact cast (9)	0.85±0.20 (7)	1.08±0.16 (7)	1.04±0.31 (7)	
Tibial nerve latency (m/s)	Arthrodesis (12)	5.02±1.87 (8)	3.66±1.42 (12)	3.51±0.76* (12)	<0.05
	Total contact cast (9)	4.61±1.10 (7)	4.74±1.12 (7)	5.87±1.43 (7)	
Tibial nerve conduction velocity (m/s)	Arthrodesis (12)	25.96±10.41 (8)	42.32±15.74* (12)	27.01±5.39 (12)	<0.05
	Total contact cast (9)	35.32±12.12 (7)	33.76±8.05 (7)	13.53±2.18* (7)	
Peroneal nerve amplitude (μV)	Arthrodesis (12)	0.57±0.15 (8)	2.07±0.57* (12)	3.17±1.59* (12)	<0.05
	Total contact cast (9)	0.51±0.15 (7)	0.53±0.90 (7)	0.33±0.52 (7)	
Peroneal nerve latency (m/s)	Arthrodesis (12)	10.69±2.50 (8)	11.80±2.51 (12)	9.40±3.71 (12)	0.23
	Total contact cast (9)	9.50±2.44 (7)	9.49±0.98 (7)	12.53±4.11* (7)	
Peroneal nerve conduction velocity (m/s)	Arthrodesis (12)	22.30±6.20 (8)	33.30±14.81* (12)	33.47±14.18* (12)	<0.05
	Total contact cast (9)	19.02±4.87 (7)	21.33±0.53 (7)	20.98±4.62 (7)	

* $P<0.05$ vs. baseline.

Table 5. Quantitative sensory testing according to treatment.

Variable	Group (total n)	Baseline (n of positive)	6 months (n of positive)	12 months (n of positive)	P-value for group- time interaction
CPT (°C)	Arthrodesis (12)	22.51±1.13 (12)	31.30±10.23* (12)	26.82±1.10* (12)	<0.05
	Total contact cast (9)	22.35±0.80 (9)	22.38±0.73 (9)	22.54±1.59 (9)	
WPT (°C)	Arthrodesis (12)	45.69±0.78 (9)	40.40±0.78* (12)	41.02±1.03* (12)	<0.05
	Total contact cast (9)	45.52±0.80 (7)	44.54±1.17 (7)	45.80±5.32 (7)	
VPT (μm)	Arthrodesis (12)	5.98±0.92 (7)	3.72±0.67* (10)	2.73±0.71* (10)	<0.05
	Total contact cast (9)	6.17±0.53 (7)	5.79±0.87 (7)	5.88±0.53 (7)	
Pinprick	Arthrodesis (12)	(2)	(7)	(7)	
	Total contact cast (9)	(3)	(3)	(3)	
Light touch	Arthrodesis (12)	(2)	(5)	(5)	
	Total contact cast (9)	(3)	(3)	(3)	

* P<0.05 vs. baseline; CPT – cold perception threshold; WPT – warm perception threshold; VPT – vibration perception threshold.

Mean peroneal nerve amplitude and latency improved after arthrodesis (P<0.05 baseline vs. 6 months, Table 4) and did not change further at 12 months. At 12 months, peroneal nerve amplitude and latency following TCC were decreased (P<0.05, Table 4). At 12 months, peroneal nerve conduction after ADS was improved (P<0.05), but was unchanged in the TCC group (P<0.05).

Quantitative sensory testing

In the ADS group 6 months after surgery, QST scores including CPT, WBT and VBT improved significantly (P<0.05). Furthermore, at 12 months, VBT was improved compared with 6 months (P<0.05) (Table 5). In the TCC group, CPT, WPT and VPT were not different between baseline and 12 months. Pinprick and light touch sensory testing improved in the ADS group after arthrodesis.

Adverse events

In the ADS group, one patient suffered from acute ankle joint arthropathy, which was managed using external fixation. No arch collapse was observed.

Discussion

The aim of the present study was to compare the effectiveness of arthrodesis plus TCC with TCC alone for the prevention, treatment and recurrence of midfoot ulcerations associated with CNA. The main finding was that although there were no differences in healing times between the 2 treatment approaches, the use of arthrodesis and TCC resulted in no ulcer

recurrence at 12 months, compared with a recurrence rate of 33.3% for TCC alone. Tibial nerve function, peroneal nerve function, temperature sensation and vibration perception were all improved after arthrodesis plus TCC, but not after TCC alone. The number of patients who were positive for pinprick and light touch sensations also increased after surgery, but not all patients recovered these sensory perceptions. These data indicate that, compared with TCC alone, the combination of arthrodesis and TCC may reduce ulcer recurrence rate by improving the functions of the tibial and peroneal nerves and sensory perception in various modalities.

The midfoot is the most commonly affected area in CNA, but an atypical deformity associated with this condition is the rocker-bottom foot, which is caused by collapse of the longitudinal arch of the foot. This, along with instability of the ankle joint, is reportedly the major cause of morbidity in CNA [18]. Joint instability resulting in repetitive nerve injury and abnormal prominent lesions of bone, which cause further stress to the nerve, both lead to a vicious cycle of neuropathy and further accelerate the development of the Charcot foot. As observed during surgery, the medial and lateral plantar nerves within the tarsal showed visible ischemia and thinning caused by bone compression (Figure 1).

Previous studies have suggested that the natural history of diabetic peripheral neuropathy (DPN) is progressive and irreversible, and that when DPN occurs in patients with a long duration of diabetes, the severity of nerve injury is more serious and it is more difficult to restore sensory and motor function [19,20]. However, this theory may not apply to unilateral Charcot foot, as evidenced by the results of the NCS and QST performed in the present study.

The NCS is regarded as an objective, quantitative, non-invasive and reliable test, and as the “gold standard” for evaluating peripheral neuropathy in thick myelinated nerve fibers. In the present study, the amplitudes and conduction velocities of the tibial and peroneal nerves in patients in the arthrodesis group were significantly improved 6 months after surgery, and the values at 12 months were similar to those at 6 months. Although the postoperative nerve conduction velocity values in the arthrodesis group remained significantly lower than normal values [21], these results nonetheless suggest that arthrodesis is effective for nerve recovery. In contrast, there were no improvements in tibial and peroneal nerve function in patients treated with TCC alone. Thus, the combination of arthrodesis with TCC appears superior to TCC alone in facilitating a recovery in the function of thick myelinated nerve fibers.

However, NCS data reflect only the conduction of thick myelinated nerve fibers, and are not sensitive to lesions in small nerve fibers [22]. Therefore, the present study also carried out QST, as this is sensitive to small nerve fibers, including sensory fibers mediating the perception of vibration, cold temperature and warm temperature. A previous study reported that vibration perception at the hallux was abnormal in subjects with CNA, and that this abnormality was asymmetric [23]. A potential confounding variable is the possibility that a Charcot foot transmits vibration less efficiently than a normal foot and thus the difference could represent simple mechanical changes in bone structure or inflammatory changes around the joint [24]; this is supported by the findings of the present study. In the arthrodesis group, vibratory sensation was improved 12 months post-surgery compared with 6 months post-surgery. In addition, CPT and WPT were also clearly improved in this group, compared with baseline. The number of patients who were positive for pinprick and light touch sensations also increased after arthrodesis, but not all the patients recovered these sensory perceptions. In contrast, the results of QST were not improved in the TCC group, mirroring the findings of the NCS. The reason for the lack of improvement in the TCC group may be that the anatomic structures had not been restored in these patients.

Although previous investigations have reported benefits of arthrodesis for the treatment of Charcot foot, the present study is the first to directly compare arthrodesis plus TCC with TCC alone for the management of midfoot ulcerations associated with Charcot neuroarthropathy. Consistent with this study, Simon et al. found that arthrodesis of the tarsal-metatarsal area followed by limb immobilization (in a non-weight-bearing cast) could improve function in patients with diabetes and Eichenholtz stage-I Charcot arthropathy, with none of the 14 patients reporting ulceration after surgery [14]. A similar utility of arthrodesis followed by immobilization (in a weight-bearing cast) has been reported in patients with Charcot foot of various

causes (including diabetes), and it has been argued that appropriate treatment of structural deformity of the foot by an orthopedic surgeon can reduce the incidence of permanent deformity, disability and ulceration [25]. Thus, it is possible that more widespread use of arthrodesis in patients conventionally treated with TCC alone may improve overall outcomes.

In the case of an unstable, non-shoeable Charcot foot, it is the authors' opinion that the most definitive long-term stability may be obtained using aggressive fusion techniques. Both the Lisfranc and midtarsal joints are susceptible to complex fracture dislocations due to CNA. In many instances, both joint segments are affected, requiring realignment and arthrodesis of the midfoot. The repair of the midtarsal joint is considerably more challenging to perform and is sometimes associated with a requirement for arthrodesis of the Lisfranc joint. In many cases, the navicular rests below the displaced medial cuneiform medially, and the cuboid is dislocated plantarly beneath the bases of the fourth and fifth metatarsals. On the lateral view, it is often possible to detect that the cuboid is plantarly dislocated beneath the metatarsal bases. An intractable ulceration often forms at the site of highest plantar pressure, lateral to the site of the plantarly dislocated cuboid. An ulcer such as this is unlikely to resolve with the use of bracing or special shoes, as evidenced by the findings in the present study: no ulcer recurrence was observed 12 months after arthrodesis, whereas a third of the patients in the TCC group suffered from recurrences. These data are supported by those of a previous study [26]. It is likely that the lack of surgical repair in the TCC group led to high pressures at the base of the foot, which in turn predisposed to ulceration and subsequent infections [27].

The present study suffers from some limitations. First, the number of patients was small. Second, these patients were from a single center and were all operated on by a single orthopedist. Larger multicenter clinical trials are necessary to draw firm conclusions about the management of Charcot foot.

Conclusions

An extended medial column arthrodesis may partly improve sensory impairment and restore protective sensation in patients with Charcot neuroarthropathy.

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Competing interests

The authors have no competing interests to declare.

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