Surgical Treatment Options for the Diabetic Charcot Hindfoot and Ankle Deformity

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Charcot neuroarthropathy (CN) is a progressive, noninfectious, inflammatory condition that leads to osteolysis-induced bone and joint destruction in patients with peripheral neuropathy.1 CN has been associated with autonomic neuroarthropathy, infection (leprosy, human immunodeficiency virus), toxic exposure (ethanol, drug related), rheumatoid arthritis, multiple sclerosis, congenital neuropathy, traumatic injury, metabolic abnormalities, and syringomyelia.2,3 However, diabetes mellitus has become the most common cause of CN in recent years. The incidence of CN is about 0.1% to 5% in diabetic neuropathy and is among the most fearful complications of diabetes mellitus.4

There are different types of classifications to describe CN that use clinical locations, radiological changes, and/or pattern of destruction. Eichenholtz5 described the first classification system in 1966. His grading was mostly a radiological evolution of the condition; this was a source of criticism, but through time it is improved and supported with clinical manifestations.1 Among the anatomic-based classifications, Brodsky6

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• Charcot • Ankle • Hindfoot • Surgery • Fixation • Diabetic neuropathy

KEY POINTS

• Charcot neuroarthropathy (CN) is associated with progressive, noninfectious, osteolysis-induced bone and joint destruction.

• Arthrodesis of the ankle and/or hindfoot is the method of choice when surgically correcting CN-related deformities in this region.

• Internal fixation, external fixation, or a combination of both can be used for the treatment.
and Sanders-Frykberg classifications include the entire foot and ankle, whereas Schon’s classification focuses on the midtarsus alone.

The Brodsky classification is based on 4 anatomic areas that are affected by the disease process. Type 1 is the most common form and constitutes about 60% of the Charcot feet. It involves all midfoot or portions of it. Type II has the main changes within the hindfoot and accounts for 30% to 35% of the Charcot feet. Type III has 2 subdivisions. Type IIIA has the changes within the ankle joint. When ankle involvement occurs, the talus is typically involved with fracture and fragmentation, leading to a non-salvageable tibiotalar (TT) joint. Type IIIB involves a pathologic fracture of the tuberosity of the calcaneus. Late deformity in this group of patients results in distal foot changes or proximal migration of the tuberosity that can lead to ulcerations and complicated with osteomyelitis. Type IV involves a combination of areas, and type V occurs solely within the forefoot. For the purposes of this article, the management of Brodsky type II and III CN, which involve hindfoot and the ankle joint (Fig. 1), are discussed.

Fig. 1. A 57-year-old male patient with CN of the ankle joint.
Primary treatment of acute CN is usually nonoperative by using off-loading techniques such as total-contact casting (TCC) or various braces. Because Brodsky’s type II and III are characterized by persistent skeletal instability, their conservative treatment may require longer periods of immobilization until Eichenholtz stage II and III are reached. Although braces or TCC can be used in the treatment, prominent malleoli makes it difficult to brace deformities of the ankle and hindfoot. When there is significant deformity and instability that cannot be controlled with careful bracing, when ulceration occurs or is inevitable, when there is associated osteomyelitis or pain, surgical management is warranted in CN. The aim of surgical treatment is to control and correct the alignment, decrease the risk of ulcerations and/or allow healing of them, treat osteomyelitis, and eventually mobilize the patient with a stable and plantigrade extremity. Surgical treatment options may include Achilles lengthening, exostectomy, arthrodesis, and primary amputation.

ACHILLES LENGTHENING

Equinus contracture of the Achilles tendon is one of the most common deformities that is seen with CN. Contracted Achilles tendon not only increases plantar peak pressures in the forefoot, it also stresses adjacent joints, frequently causing them to collapse and develop into nonreducible deformities. Because of this, Achilles tendon lengthening can be used in conjunction with CN-related arthrodesis procedures to improve alignment of the ankle and hindfoot to the midfoot and forefoot.

A percutaneous technique with 3-stab incisions is often preferred but the procedure has been shown to have some risks like overlengthening, iatrogenic rupture of the tendon during the procedure, and late rupture after ambulation secondary to a weakened tendon. Overlengthening may result in calcaneal gait, which may also complicate the process with the development of heel ulceration. To avoid overlengthening, selective release of medial plantar fascia was described, and Kim and colleagues reported a 67% healing rate of forefoot ulcerations and no complications with this technique. Holstein and colleagues reported a 10% rupture rate after percutaneous Achilles tendon lengthening in 68 patients’ ulcerated neuropathic feet. There is risk of hematoma formation, infection, and potential amputation after Achilles rupture in diabetic patients; because repair of the tendon is not feasible and is not usually recommended in this patient population, Stapleton and colleagues recommended to treat ruptures with an ankle or tibiotalocalcaneal (TTC) arthrodesis.

EXOSTECTOMY

Exostectomy is most effectively used for Brodsky type 1 deformities, which involve the tarsometatarsal joints. Unlike the midfoot, exostectomy is rarely successful at the level of the ankle and hindfoot because of the underlying malalignment. It can be used to permit healing of a chronic ulceration around malleoli, which is usually associated with a coronal plane deformity. It is also useful to minimize the deformity and consolidation-related bulky appearance around the ankle.

ARTHRODESIS

Arthrodesis of the ankle and/or hindfoot is the method of choice when surgically correcting CN deformities in this region. The goal of the arthrodesis procedure is to realign the foot on the leg and convert the deformed foot and ankle to a plantigrade one that is now stable, braceable, and walkable. A stable pseudoarthrosis or so-called fibrous ankylosis is also accepted as sufficient for a good functional outcome in this patient...
Successful arthrodesis requires careful removal of all cartilage and debris, debridement to bleeding subchondral bone, meticulous fashioning of bone surfaces for contact, complete debridement of soft tissues, and stable fixation. In this process, osteotomies may also be required to correct the alignment of the ankle and hindfoot.

If the deformity is isolated to the subtalar joint and/or Chopart joints, triple arthrodesis can be the procedure of choice. However, ankle and hindfoot involvement further complicates with collapse and destruction of the talus body, which increases instability around the ankle. Deformities involving the body of the talus and/or ankle are usually treated with a TTC or tibiocalcaneal (TC) arthrodesis depending on the involvement of the talus. Pantalar arthrodesis is another option in these patients; however, TTC or TC arthrodesis is more preferable because they permit some motion at the transverse tarsal joints and this motion allows a small amount of plantarflexion and dorsiflexion.

The choice of fixation (ie, internal, external, or both) depends on several factors. Internal fixation is not recommended in cases with poor soft tissue envelope, active infection, severe deformity preventing acute correction, and poor bone quality. It is generally preferred to combine internal and external fixation in patients with morbid obesity, when there is a high risk for fixation failure or a need for soft tissue protection.

There are several options for internal fixation in the hindfoot and ankle. If a triple arthrodesis is performed, fixation is usually performed with multiple screws, but one has to be careful with their usage because they may not achieve adequate fixation for the large forces that will be placed across the joint (Fig. 2). For arthrodesis procedures that extend across the ankle joint, screws, intramedullary nail, external fixator, locked plates, blade plate, and a combination of internal and external fixations can be used.

**Intramedullary Nailing**

The retrograde intramedullary arthrodesis nail offers stable intramedullary fixation and load sharing, and because of its intramedullary location, it can resist large forces. Because of these advantages, studies reporting correcting ankle deformities in CN are more likely to use intramedullary nails (Figs. 3–5).

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**Fig. 2.** Same patient as shown in **Fig. 1**, 2 years after surgery. Please note the stable and plantigrade weight-bearing foot achieved with multiple internal fixation screws.
In 2006, Caravaggi and colleagues\textsuperscript{32} reported results of 14 patients with CN involvement of the ankle and hindfoot. The investigators found that 10 patients (71.4\%) achieved a solid ankle fusion, whereas 3 patients (21.4\%) achieved a stable fibrous union that allowed ambulation in a brace. Three patients (21.4\%) had hardware complications that necessitated removal, and one patient (7.2\%) did eventually require a transtibial amputation for postoperative osteomyelitis.

Dalla Paola and colleagues\textsuperscript{33} published the results of pantalar arthrodesis using an intramedullary nail in 18 patients with CN. Of the 18 cases, 14 resulted in stable union; the remaining 4 patients achieved a fibrous union. They did not observe any major complications, and along with satisfactory plantigrade positioning of the foot, limb salvage was accomplished in all 18 patients. Similarly, Siebachmeyer and colleagues\textsuperscript{23} reported the outcomes of 20 patients' 21 feet with CN who underwent retrograde intramedullary nail arthrodesis. Limb salvage was achieved in all patients after a mean follow-up of 26 months and all patients except one regained independent mobilization in their study. One patient required revision surgery because of a broken nail, and they observed migration of distal locking screws when standard screws had been used but not with hydroxyapatite-coated screws (Fig. 6).

Recently, Ettinger and colleagues\textsuperscript{15} published their results with surgical treatment of CN ankle involvement. Of the 58 patients, 38 were treated using intramedullary nail arthrodesis, 19 using an external fixator and 1 patient receiving neither. They achieved 100\% fusion rate after intramedullary nail arthrodesis.

**External Fixation**

Although Farber and colleagues\textsuperscript{34} and Pinzur\textsuperscript{35} concluded that using external fixators leads to nonunion of TTC arthrodesis more frequently than does internal fixation, in cases of infection or poor soft tissue coverage, external fixation may be the only viable option. It is also biomechanically shown that in cases where internal fixation is not
appropriate, external ring fixation may be used with confidence.\textsuperscript{36} External fixation also allows continued and immediate weight-bearing to patients who are not able to remain non-weight-bearing or in patients with a history or increased risk of deep venous thrombosis\textsuperscript{9} (Fig. 7).

Fabrin and colleagues\textsuperscript{37} evaluated the results of 12 ankles treated with external fixation for TT or TTC arthrodesis for CN with the presence of ulceration. They showed an overall salvage rate of 92% with only one leg requiring transtibial amputation due to

Fig. 4. Nine months after the original operation, the same patient as shown in Fig. 3 developed CN in the ipsilateral ankle joint (A) followed by a TTC arthrodesis and intramedullary nailing (B).
loosening of the distal pins from osteopenic disintegrating bone. In addition to the amputation, the complication was drainage from pin holes in 5 and superficial wound infection in one patient. In their study, 5 of 7 (71.4%) of the patients with isolated TT arthrodesis went on to solid union, whereas only 1 of 5 (20.0%) patients requiring TTC fusion obtained a solid union. The remainder of the patients ended with a stable fibrous union that was functional and this was accepted as a success.

Zarutsky and colleagues38 looked at the use of external fixation for salvage ankle arthrodesis. Of the 43 patients included in the study, 11 patients were treated for CN of the ankle, 5 without additional internal fixation and 6 with internal fixation. All 5 patients without additional internal fixation were able to be salvaged, although one patient required using a wheelchair because of an unstable nonunion. They reported 8 major complications in CN patients. There were 3 (7.3%) below-knee amputations in the whole study group of whom only one was related with CN-associated deep-space infection.

In 2009, Karapinar and colleagues39 reported 11 patients who had undergone CN ankle reconstruction using Ilizarov external fixators. Of the 11 patients, 10 had successful union at an average of 16.1 weeks and were able to walk freely. The remaining one patient resulted with a fibrous nonunion. At final follow-up, excellent results were obtained in 3 patients, good in 6, fair in 1, and poor in 1.
In their 2016 study, Ettinger and colleagues used external fixators for ankle CN in 19 of 58 patients. They reported 84.2% fusion rate in external fixator group. In their retrospective study, 2 patients developed deep infectious complications that led to persistent nonunion and ultimately required transtibial amputation.

Condylar Blade Plate

Myerson and colleagues reported the results of internal fixation with adolescent condylar blade plate in 30 patients, 26 of whom had diabetic neuroarthropathy with

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**Fig. 6.** A 26-year-old patient treated with intramedullary nailing for TTC arthrodesis. Preoperative clinical and radiographic pictures (A) followed by clinical and radiographic appearance 4 months after intramedullary nailing (B).
talar fragmentation. The surgery was performed with removal of remaining talus, placement of bone graft with antibiotic powder to fill the defect, and fixation with a rigid plate. Fusion was achieved in 28 of 30 patients on average of 16 weeks. There were 2 nonunions, 2 stress fractures at the proximal plate, and 3 superficial infections.

In 2010, Cinar and colleagues reported 100% limb salvage rate in 4 patients with CN of the ankle. They used a 95°C angled blade plate via a posterior approach for TC arthrodesis and achieved fusion by 5 months in 3 of 4 patients; in the other patient, a stable fibrous ankylosis was achieved (Fig. 8).

**Locking Plates**

Although locking plates are mostly used for the fixation of midfoot CN, they can also be chosen for internal fixation of TC or TTC arthrodesis. Ahmad and colleagues reported 18 cases of TTC fusion using a humeral locking plate, and DiDomenico and Wargo-Dorsey reported on TTC fusion using a femoral locking plate. Similarly, Aikawa and colleagues achieved successful fusion with the use of humeral locking plates for TC arthrodesis in 3 patients. In their study, all patients achieved bony union with a plantigrade foot and without any skin complications.

**Combined Fixation**

Internal and external fixation can be combined to improve mechanical stability, control adjacent joint mobility, protect the soft tissues, and realign the osseous segments while providing compression and limiting motion to optimize bone healing and
Hegewald and colleagues\textsuperscript{46} combined internal and external fixation in 22 patients with CN. In 6 of 22 patients, TTC arthrodesis were performed for ankle involvement. Two patients (33.33\%) in the ankle group developed recurrent deformity, subsequent fixation failure, and required below-knee amputation.

In their series of 52 patients, DeVries and colleagues\textsuperscript{30} combined intramedullary nailing with external fixation for 7 patients. There was successful salvage resulting in maintenance of limb in 5 patients (71.4\%), and there was no statistically significant difference between the 2 groups in terms of hardware removal, rates of complications, or need for revision surgery.

**BONE GRAFTS**

Bone grafts can be used to address osseous defects and optimize bone healing in the reconstruction process of diabetic CN-associated deformities. There are several options that can be used. Among these, autogenous bone grafts are the gold standard because of complete histocompatibility and no risk for disease transmission; however, their use is associated with donor-site morbidity, limited supply, and increased surgical time.\textsuperscript{47} The most commonly used donor site for autograft harvesting is iliac crest for ankle arthrodesis in CN that is usually harvested from the contralateral hip.\textsuperscript{48} Proximal tibia, distal tibia, calcaneus, and fibula can also be used for graft harvesting.\textsuperscript{49} The fibula can be used as a strut graft to fill defects and buttress constructs or as an intramedullary graft.\textsuperscript{50,51} It can also be prepared as corticocancellous graft to use at the arthrodesis site.

Joint preparation for arthrodesis in CN patients usually leads extensive bone loss, especially in cases with osteomyelitis. Because of the limited supply of autografts, allografts can be used in cases with large bone defects. Femoral head and iliac crest allografts are effective for filling these defects and providing structural support. They can also be used for the restoration of talar height and leg length.\textsuperscript{52,53} However,
one has to remember that without rigid fixation (which is especially important in cases with CN) abundant use of allograft will not guarantee fusion and can even predispose the surgical site to infection (Figs. 9 and 10).

In cases with osteomyelitis, antibiotic-impregnated cement can also be used as a void filler to help soft tissue to heal, to eliminate dead space at the infected bone cavity following surgical debridement, and control infectious process locally without systemic side effects associated with systemic antibiotic use.54–56

PRIMARY AMPUTATION

Primary amputation is a choice for some patients, and it may be the most beneficial treatment in certain situations. Patients who are candidates for primary amputation have non-reconstructable peripheral vascular disease, extensive open wound(s) that

Fig. 9. Preoperative anteroposterior and lateral ankle radiographs (A) of an ankle CN that was operated with allograft application and K-wire fixation in another facility (A). Five months after her first surgery, the patient presented with pseudoarthrosis, fistulization, and serohemorrhagic drainage. Revisional surgery included combined internal and external fixation and autografting by using the distal fibula (B). Final anteroposterior and lateral ankle radiographs 4 months after the revisional surgery (C).
preclude adequate soft tissue coverage, extensive osteomyelitis, multiple comorbidities like renal failure, or a nonambulatory patient and psychiatric disease precluding compliance with the prolonged postoperative regimen. In their recent study, Schneekloth and colleagues reviewed published data regarding the surgical management of CN between 2009 and 2014. They included 30 studies in their review and found an overall amputation rate of 8.9% in patients with CN. Although this number does not reflect the primary amputation rate, it is shown that patients with CN and foot ulcers are 12 times more likely to require a major amputation than patients with CN but without foot ulcers.

Usually below-the-knee amputation is preferred, but Altindas and colleagues suggested a 2-stage Boyd operation technique for late-stage CN feet. All of the patients in their study had hindfoot involvement, and they reported successful results without any complications, with a mean follow-up of 2.1 years with their technique.

**SUMMARY**

CN is associated with progressive, noninfectious, osteolysis-induced bone and joint destruction. When ankle and/or hindfoot is affected by the destruction process, the
clinical presentation is further complicated with collapse and destruction of the talar body, which increases instability around the ankle. In this patient population, arthroposis is the most commonly used surgical procedure. Internal fixation, external fixation, or a combination of both can be used for the surgical reconstruction. Decision making between them should be individualized according to the patient characteristics.

REFERENCES