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Midfoot and Hindfoot Charcot Joint Deformity Correction with Hexapod-assisted Circular External Fixation

Noman A Siddiqui[1] and Amanda Pless[2]*

[1]Department of Podiatric Surgery, Rubin Institute for Advanced Orthopedics, International Center for Limb Lengthening, Sinai Hospital of Baltimore, 2401 W. Belvedere Ave, Baltimore MD, 21215, USA

[2]Our Lady of Lourdes Memorial Hospital, 169 Riverside Drive, Binghamton, NY 13905, USA

Abstract

Charcot Neuroarthropathy (CN) is a debilitating condition that results in complex foot and ankle deformity. Loss of normal pedal architecture can cause gait dysfunction as well as soft-tissue compromise and limb loss. Foot and ankle surgeons have treated CN with and without operative intervention. Operative techniques to treat midfoot and hindfoot deformities with internal and external fixation have been described in the literature. Despite a lack of consensus as to the fixation method, articles have attempted to identify features that necessitate operative intervention. This article proposes recommendations for surgeons to utilize when correcting CN with hexapod-assisted circular external fixation.

Keywords: Charcot neuroarthropathy; Ilizarov external fixation; Hexapod; Midfoot charcot; Hindfoot charcot

Key Points

- Charcot deformity of the midfoot and hindfoot is complex.
- Operative treatment should be reserved for feet that are unstable, non-braceable, have wounds, and are at high risk for amputation.
- Hexapod-assisted circular external fixation can be used in feet with good bone stock and a large angular deformity.
- Surgery should be performed in two stages to obtain and maintain correction.

Charcot Neuroarthropthy (CN) is a debilitating and aggressive process affecting the bones, joints, and soft tissues of the foot and ankle. The process can ultimately lead to deformity and disfigurement of the affected foot and ankle. The prevalence of the disease is between 0.08% and 7.5% in patients with diabetes mellitus [1]. The pathogenesis of the disease process is thought to be multifactorial in nature resulting in a localized inflammatory state that leads to bony destruction, dislocation, and subluxation [2]. These challenging cases require surgical intervention for reconstruction of the foot and ankle to address instability, major osseous destruction, and deformity that cause ulceration and infection. The goals of surgical intervention include creation of a stable, plantigrade foot that is both ulcer- and infection-free and ultimately able to be placed in a brace for ambulation [3].

In recent years, many studies have been published on the efficacy and indications for various Charcot deformity treatments including conservative methods, internal fixation, "super constructs," external fixation, and a hybrid of internal and external fixation methods [2,4,5]. While no definitive consensus has yet been reached as to the superior method of fixation, attempts have been made to discuss the rationale for various fixation methods [6,7]. One method of fixation that has gained more attention is hexapod-assisted circular external fixation. The principles of traditional Ilizarov circular fixation are used in conjunction with a software program to guide six-axis correction. The goal of this article is to assist surgeons in identifying patients for Charcot reconstruction of the midfoot and hindfoot with a hexapod-assisted circular frame.

Classification of Charcot Neuroarthropathy

Several classification systems for CN staging have been presented throughout the years. In 1966, Sidney Eichenholtz developed a three-stage system based upon radiographic evaluation [8]. Stage I, the developmental stage, consisted of bony debris, fragmentation, and dislocation. Stage

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***Correspondence:**
*Noman A Siddiqui, Department of Podiatric Surgery, Northwest Hospital, Rubin Institute for Advanced Orthopedics, International, Center for Limb Lengthening, Sinai Hospital of Baltimore, 2401 W. Belvedere Ave, Baltimore MD, 21215, USA,
E-mail: nsiddiqu@lifebridgehealth.org*

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II, coalescence stage, included absorption of fine debris, sclerosis, and fusion of fragments. Stage III, reconstruction and reconstitution stage, consisted of lessened sclerosis, rounding of fragments, and attempts at reformation of joint architecture [9].

With greater imaging modalities available today, anatomic classifications are widely utilized, especially those of Sanders and Frykberg [10], Brodsky and Rouse [11], and Schon [12]. The Schon classification [12] is divided into four types based upon anatomic location of deformity: Lisfranc, naviculocuneiform, perinavicular, and transverse tarsal. Additionally, three stages of degree of collapse in the sagittal plane on weight bearing radiographs are included. Stage A shows the least degree of collapse (i.e., above the level of the plantar surface of the foot). In stage B, the deformity collapses to the level of the plantar surface. In stage C, the midfoot has attained a rocker bottom deformity below the plantar surface of the foot and is prone to ulceration [12].

Indications for Use of External Fixation

Benefits of surgical intervention via static and dynamic circular external fixation have been well documented in patients with CN deformity. Indications include the following:

- Midfoot/hindfoot/ankle instability
- Non-reducible bony deformity
- Bony defect (with or without osteomyelitis)
- Soft-tissue ulceration (with or without infection)
- Ambulatory dysfunction that cannot be corrected through bracing

The indications for hexapod-assisted circular fixation include the ones mentioned above. However, the authors feel that the secondary benefits are what can make hexapod-assisted circular fixation, at times, superior to a static Ilizarov device or internal fixation. Hexapod-assisted circular fixation will allow the surgeon to:

- Realign malaligned bony segments precisely
- Maintain foot and ankle height and length without decreasing cubic bony contents via wedge resections
- Allow for concomitant management and gradual correction of hindfoot and midfoot deformities
- Address large angular, translational, and rotational deformities without significant risk of neurovascular compromise
- Convert to earlier weight bearing
- Manage soft-tissue defects
- Perform multi-stage operations that allow for delayed definitive treatment in the presence of active bony or soft-tissue infection

These factors should be considered when planning surgical intervention for patients experiencing deformity secondary to CN. Identifying which patients would benefit from the hexapod-assisted correction is equally as important as the indications and benefits of surgery. The authors recommend the following guidelines:

- Patients should have good overall bone stock in the midfoot and hindfoot. Though midfoot and hindfoot Charcot joints can lead to bone loss/dissolution, having large bony segments that have not been ravaged by CN is important in reconstruction of "normal" pedal architecture (Figure 1).

Figure 1: Midfoot Charcot deformity. Equinus of the hindfoot and dorsal subluxation of the midfoot onto the hindfoot creates a "bayonet" deformity. This deformity can progress to rockerbottom foot type. Lack of bone loss/dissolution serves as good indication for hexapod assisted correction. Copyright 2017, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore.

Figure 2: Joint subluxation without fracture can be accurately re-aligned with hexapod-assisted circular external fixation. Large angular deformity can occur in multiple planes and create significant soft-tissue deformity that needs to be addressed gradually. Acute correction will require large bony resections that may not be desirable in certain circumstances.

- If patients have subluxation of joint segments without significant bone loss or fractures, the joints can be realigned precisely utilizing the software programming (Figure 2).
- Midfoot "bayonet" deformity (Figure 1) is a common deformity that lends itself to this method. In this correction, a "butt joint" can be used to raise the lateral column and realign the pedal arch.
- Large angular deformities may be present in multiple planes (Figure 2).

These features can be difficult to address in the midfoot and hindfoot without significant shortening of the limb. Hexapod-assisted circular fixation allows for gradual correction in all planes. Important at risk soft-tissue and vascular structures can be protected and accounted for during this correction.

Recent comparisons of internal and external fixation for limb reconstruction and salvage has yielded promising results. In 2012, a review of the literature by Dayton "et al". [13] showed that while external fixation was used in cases with a higher degree of complication, external fixation had greater odds of success over internal fixation. Lee "et al". [6] in 2016 showed via literature review that external fixation resulted in decreased risk of amputation, wound healing problems, deep infections, need for further surgery,

Figure 3: Saltzman view provides a frontal plane relationship of the hindfoot with respect to the long axis of the leg. Copyright 2017, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore.

and intraoperative and perioperative fracture when compared with internal fixation. While more studies are needed, it is clear that external fixation is a reliable choice for deformity correction in CN. Additionally, advances in hexapod frames and improved software have decreased the complexity previously associated with dynamic framing options to address Charcot reconstruction.

Clinical Presentation

Upon clinical presentation of patients with CN, it is important to thoroughly assess both the deformity and the individual to determine if the patient can understand the demands associated with hexapod-assisted external fixation. The presence of co-morbidities, control of HbA1c, social support system, vascular status, tobacco or recreational drug use, and nutritional status must be optimized in these candidates prior to any surgical intervention.

Radiographic Evaluation

When evaluating the deformity, plain radiographs and 3-D weight bearing Computed Tomography (CT) scans are the senior author's (NAS) imaging modalities of choice. These imaging studies allow complete understanding and quantification of sagittal, frontal, and transverse planes as well as rotational deformities of the foot and ankle. 3-D weight bearing CT scans provide a comprehensive assessment of any fractures or dislocations present in the foot or ankle. The surgeon can address them intraoperatively via fusions, realignment, and/or osteotomy. Preoperative measurements allow the surgeon to use hexapod software for pre-planning of length and breadth of correction.

Plain film radiographs should include standard views of the foot and ankle. The senior author (NAS) routinely obtains limb length assessment films and Saltzman views. Erect full length standing AP views radiographs are obtained that visualize the lower extremity from the hip to the foot. This view can assist in planning potential shortening and/or simultaneous limb lengthening that can occur during treatment. Saltzman views provide frontal plane relationships of the hindfoot, ankle, and lower leg (Figure 3) [14]. In hindfoot CN cases, the varus and valgus relationships can be visualized accurately on Saltzman views. Some hexapod software programs allow for deformity planning and determination of proximal and distal reference points prior to surgical intervention.

Case Studies

We present two patients who were selected for complex Charcot

Figure 4: Clinical appearance of Charcot dislocation. A, Simulated weightbearing of right foot. B, Axial appearance of the foot.

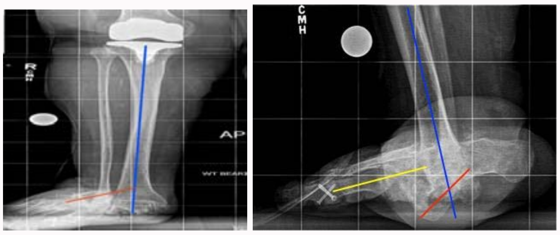

Figure 5: A, AP view of the ankle shows subtalar joint dislocation and angular deformity. B, Lateral view shows significant shortening of the hindfoot on the ankle.

reconstruction in the midfoot and ankle with a hexapod device. The midfoot and hindfoot CN surgeries were performed by the senior author (NAS).

Case 1: Hindfoot charcot deformity

A 62-year-old woman with type II diabetes presented with longstanding right foot and ankle Charcot deformity. She had experienced the deformity for more than 1 year after failure of conservative treatment and bracing. She had a history of rheumatoid arthritis, deep vein thrombosis with pulmonary embolism, hypertension, and thyroid disorder. These medical issues were well managed by her primary care physician. Her HbA1C was optimized and within normal limits.

The patient had an obvious hindfoot and forefoot dislocation with shortening on to the ankle joint in a valgus attitude (Figure 4). Her foot and hindfoot were laterally displaced and subluxed with respect to the long axis of the tibia, and soft-tissue thickening was observed over the talar head. She had no history of open wounds, but significant callus and soft-tissue redundancy were noted medially. Her foot was not freely reducible and was locked in a valgus position with respect to the ankle and leg.

A 3-D weight bearing CT scan was obtained as well as simulated weight bearing plain film radiographs (standard foot and ankle views, erect full length standing AP view, Saltzman view). The radiographs revealed a 5.5-cm lateral displacement of the calcaneus with approximately 7 cm of shortening of the calcaneus onto the ankle joint (Figure 5). The hindfoot was in a 45-degree valgus deformity with respect to the long axis of the tibia. A complete dislocation through the subtalar joint without fractures of the ankle, talus, and calcaneus was observed. No fractures, bony dissolution, acute osseous destruction, or evidence of osteomyelitis were noted.

A two-stage external fixation surgical strategy was employed to correct the deformity. The goal of the first stage was to distract and realign the foot and subtler joint on the ankle via hexapod-

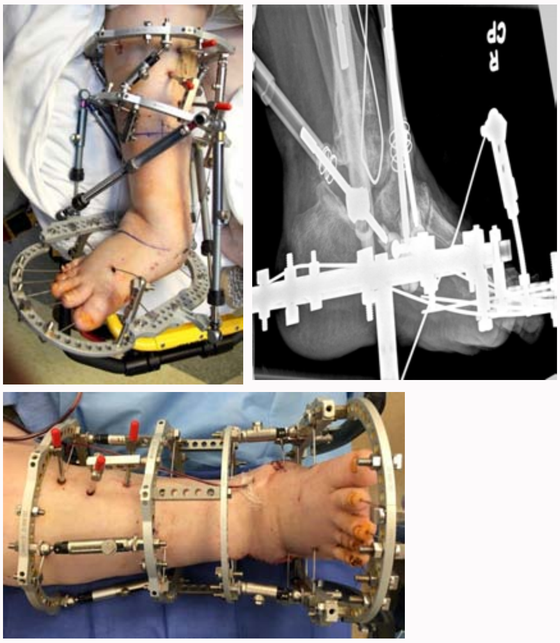

Figure 6: A, Two-stage approach was utilized. During the first stage, the gradual correction was used to create axial distraction of the limb. B, Radiographic presentation 3 weeks after distraction. Appreciate the subtalar joint and calcaneus distraction. C, Conversion to hindfoot fusion with minimal bony loss.

assisted external fixation over the course of 3 weeks (Figure 6). The second stage of the surgery converted the dynamic portion into a static construct for focused fusions of the hindfoot and ankle. In the postoperative period, the patient was allowed to be weight bearing as tolerated with the assistance of the walker. In the postoperative period, the patient had a relatively uneventful course. She did not develop any pin-site infections; however, one pin had to be removed for soft-tissue irritation. Once radiographic evidence of bony fusion was noted, the external fixation device was removed. The patient was converted to full weight bearing in a protective boot and will maintain this boot for 1 year. After 1 year, she will be allowed to transfer to regular extra depth diabetic therapeutic shoes.

Case 2: Midfoot charcot deformity

A 72-year-old man with type II diabetes presented with a recent diagnosis of CN. The patient reported a progressively collapsing medial arch with formation of a pre-ulcerative lesion on the midfoot. No tissue breakdown was observed. After radiographic evaluation, a midfoot Lisfranc Charcot deformity with collapse of the midfoot and bayonetting of the forefoot on the hindfoot was apparent (Figure 7). The patient was at risk for developing ulceration; therefore, a two-stage correction with hexapod-assisted external fixation was planned. During the first stage, the procedures to correct equinus and apply the hexapod were performed (Figure 8). The patient carried out the strut adjustments over a course of 2 weeks and then returned to the operating room for the second stage of treatment. During stage two, the gradual correction frame was converted to static external fixation. Multilevel focused joint fusions of the forefoot, midfoot, and hindfoot were carried out. The ankle was spared. Radiographic healing was noted approximately 10 weeks after application of the hexapod in stage one, thus allowing frame removal (Figure 9).

Postoperative period

The postoperative protocol for each patient depends on the frame construct and which stage of deformity correction the patient has completed. The senior author (NAS) does not allow patients to bear weight on the external fixator during the dynamic correction phase; however, patients may begin gradual to full weight bearing with the assistance of ambulation devices once they have entered the static phase of the correction.

Figure 7: Midfoot Charcot deformity with progressive collapse of pedal arch. A, AP view radiograph of the foot B, Lateral view radiograph of the foot.

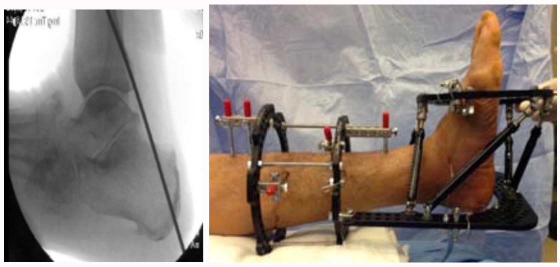

Figure 8: A, Acute equinus correction was maintained with a temporary extra-articular fixation pin. B, Application of hexapod apparatus for gradual correction of deformity.

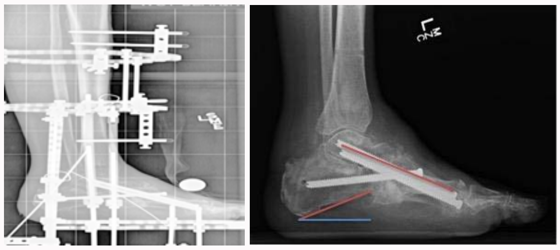

Figure 9: A, Lateral view radiograph with external fixation construct in place. After correction was achieved, it was maintained with intramedullary foot fixation. B, Lateral view radiograph obtained after frame removal. Arch is restored, and solid fusion is noted in the midfoot.

Though not necessary for all patients, many patients will eventually require admittance to either an inpatient rehabilitation or acute skilled nursing facility postoperatively for physical therapy and/or occupational therapy. Strut adjustments are initiated once skin incisions have healed (approximately 10 days). Pin care is based on surgeon preference, and the senior author (NAS) allows patients to shower after skin healing is noted. The external fixator remains in place until signs of radiographic bony healing, which can be typically 3 to 4 months. Computed tomography scans can be helpful in evaluating the fusion sites if hardware impedes accurate radiographic evaluation of fusion sites. Protected weight bearing is carried out in a boot or protective ankle-foot orthosis for up to 1 year. The patient transitions to supportive diabetic shoe wear and then ankle-foot orthoses. In both cases, it is important to protect the fusion site for the lifetime of the correction with a custom-molded ankle-foot orthoses.

Complications

The most common complication associated with external fixator assisted surgical intervention of CN is pin-site infection, occurring in 8.4% to 100% of the cases reported in the literature [15,16]. However, most of these infections are superficial and treatable via a short course of oral antibiotics and local wound care [17]. Rare complications include deep-tissue infections, osteomyelitis, pin loosening, delayed mobilization, hardware breakage or failure, non-tolerance of external fixator device, loss of fixation, or nonunion [17,18]. Many of these complications may result in the removal of pins or the frame entirely. In the senior author's (NAS) experience, localized pin-site infections are the most common complication seen in this patient population. To lower pin-site complication rates, the senior author educates patients about pin-site care and advises patients to use chlorohexidine sponges for localized pin-site care.

Discussion

Both cases illustrate examples of successful utilization of a hexapod device. In case 1, the external fixator gradually distracted the bony and soft-tissue structures that had adapted to a chronic dislocation. The dorsal lateral dislocation of the calcaneus through the subtalar joint was maintained in a non-reducible valgus position due to the Achilles and peroneal tendon contracture. Axial distraction provided enough stretch of the Achilles, peroneal and tarsal tunnel contents to safely realign the bony elements of the subtalar joint. Bony distraction past the fibular malleolus and talus facilitated anatomic realignment of the hindfoot on the ankle. A key technical tip during this procedure is to secure the talus in the mortise. This was accomplished by placing non-tensioned crossing wires through the talus and securing them to the proximal non-moving fixation block. Not securing the talus can create varus or valgus rotation within the mortise during large angular corrections. After successful alignment is achieved in the second stage, accurate and adequate preparation of the joint surfaces can be performed. The hexapod can be converted to a joint compressive frame to achieve fusion of the hindfoot segments.

In case 2, the same principles of a staged operation were used. Midfoot Charcot deformity poses similar challenges of soft-tissue deformity and bony structures impingement, which maintain the foot in a deformed, maligned position. In midfoot Charcot, the collapse of the medial column in conjunction with lateral column subluxation creates a radiographic presentation in which the forefoot "bayonets" on the hindfoot (Figure 1). The Achilles tendon gains a mechanical advantage with collapse and further maintains the hindfoot complex in an equinus position. The forefoot dorsally displaces and locks over the hindfoot. The locked position can be maintained by consolidating fractured cuneiforms along with the extensor tendons and tibialis anterior tendon. The peroneal tendons further create a transverse plane deformity by acting on the forefoot.

The hexapod can address the hindfoot and midfoot/forefoot deformity simultaneously by creating a "mitre" frame construct. This complex construct acts as a double-level hexapod for independent guided correction of the ankle/hindfoot and midfoot/forefoot. Though an excellent method for correction, the senior author (NAS) recommends simplifying the construct in Charcot joint patients by utilizing a "butt" frame design. The "butt" frame construct can decrease the complexity of the correction for the surgeon. The hindfoot equinus deformity, with this method, is addressed acutely during the first stage of correction. In the first stage, the equinus contracture of the Achilles tendon can be accomplished by surgeon-preferred method of Achilles lengthening. Once the calcaneal pitch is restored, it is temporarily stabilized by placement of an extra-articular pin from the calcaneus into the posterior tibia (Figure 8a). This simplifies the correction by letting the surgeon focus on returning the malaligned midfoot and forefoot to a normal hindfoot. A technical tip is to place "stirrup" wires across the area of distraction and connect them to the distal ring. If needed, an open or percutaneous midfoot osteotomy should be performed. The need for osteotomy is based on the degree of bony consolidation. A consolidated midfoot deformity usually requires osteotomy. Bony dissolution or non-united midfoot fractures, generally, will not require osteotomy. Prior to any angular correction or translation, the surgeon must obtain axial distraction of the forefoot to decompress the bony and soft-tissue structures of the midfoot. Not allowing for adequate distraction will make it difficult to accurately re-align the lateral Meary's angle or allow the midfoot cuneiforms to be exposed from the dorsal dislocated foot. Once alignment and distraction is achieved, the goal of the second stage should be to maintain correction by obtaining arthrodesis from the hindfoot to the forefoot. This requires adequate preparation of the articular surfaces of the medial and lateral column bony structures. Compression of the arthrodesis complex can be done utilizing the frame but is difficult to execute. The author recommends placement of axial wires or intramedullary placement of wide diameter screws through the medial and lateral columns of the foot (Figure 9a/9b). The hexapod frame can be converted to a static device to protect the arthrodesis site during the healing period.

Summary

CN continues to remain a devastating, limb-threatening disease. Management can be complicated by complex medical and social challenges. Correction of CN is well documented by techniques for bony deformity reconstruction. Correction via external fixation has been shown to be an appropriate method for surgical stabilization of an affected limb. When using a multiplanar hexapod-assisted external fixator system, the authors have the following recommendations:

- Knowledge of the Ilizarov technique is critical to successful application of any external fixator. The goal of hexapod-assisted surgery is to obtain the correction in two stages: the first stage consists of gradual correction and the second stage is the conversion of the dynamic frame to a static frame to maintain the correction.

- Hexapod-assisted correction requires the use of a software program. Becoming familiar with entering the deformity parameters into the software program will ensure a successful treatment outcome with minimal adjustments in the perioperative period. Continued medical education and mock computer simulations can assist the novice surgeon in learning various systems.

- Identifying appropriate candidates for hexapod application, as mentioned earlier, is critical to achieving an accurate outcome. Candidates should have the following features/requirements:

- Good bone stock with minimal bone loss
- Individuals with joint subluxation without fractures
- Large angular deformity
- Concern for soft-tissue quality
- Need to maintain limb and foot length

The surgeon must remember that the goals of Charcot deformity correction are to create a stable, braceable foot that allows for community ambulation to accomplish most activities of daily living [3,19]. Properly executed hexapod-assisted Charcot deformity correction is a powerful and valuable tool in the foot and ankle surgeon's armamentarium in achieving these goals.

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