Use of External Fixation for the Management of the Diabetic Foot and Ankle

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Introduction

Charcot arthropathy is an overwhelming complication of peripheral neuropathy. It occurs in approximately 30 % of those individuals afflicted with peripheral neuropathy, with diabetes mellitus being the most common cause in the United States [1]. The consequence of this progressive and debilitating condition is pedal joint subluxations, dislocations, fractures, and extensive osseous architecture destruction resulting in deformity of the foot and ankle and ulcerations. When evaluating patients, the authors assess the foot and ankle for the stage and location of arthropathy, the presence of any ulcers, and whether the patient has any soft tissue and the bone infections.

As explained in Chap. 4, the temporal classification system of Eichenholtz [2] discusses Charcot arthropathy as it progresses through three stages. These are described as developmental, coalescence and reconstruction, with Shibata et al., adding an additional phase (stage 0) to describe the foot at risk, which precedes the developmental phase and which radiographic findings are negative [3]. Treatment often consists of nonoperative treatment including a total contact cast immobilization until bony consolidation occurs. Non-weightbearing produces an increased load on the contralateral foot, which can then lead to ulceration, precipitation of Charcot arthropathy, and osteopenia. Maintaining non-weightbearing status is difficult for this patient population for various reasons including obesity, diminished proprioception, and muscle atrophy. Despite early recognition and treatment, the disease process can result in osseous and soft tissue deformities, which can lead to a deformed foot position and the presence of equinus, all of which can be difficult to properly shoe, brace, and/or offload. This places the individual at risk for ulcerations, infections, and subsequent limb loss [1, 4]. Once the stage of Charcot has been determined, it is important to note the anatomic location of the Charcot deformity. Various authors have classified the Charcot foot and ankle based on its anatomic location [5–7]. Although useful, none have been validated as predictive of outcomes. However, the authors feel that the Charcot location has a significant determination on the type and success of treatment rendered for the deformity.

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Next, it is important to identify the presence of an ulcer. Ulcers become more common when patients present with midfoot Charcot deformities, especially if the deformity progresses proximally. The key to managing these deformities is to allow for bony consolidation of the dislocation. However, when this consolidation results in a significant deformity, or recurrent ulceration occurs, surgical intervention is typically performed. A collapse of the medial column of the midfoot tends to produce ulcers along the plantar medial aspect of the foot. This often occurs when there is peritalar dislocation of the navicular-cuneiform joint causing the talus to dislocate medially and plantarly. Lateral ulcers are due to a disruption of the lateral column. This collapse is exacerbated by the effect of the ground reaction vector that is initiated at heel strike. In addition, the presence of an equinus contracture and the pull of the tibialis anterior tendon further exacerbate the lateral column disruption. This produces a "bayoneting" affect of the forefoot on the hindfoot, which produces a classic "rocker bottom" deformity of the foot. Prolonged weightbearing on these unstable midfoot deformities acts to produce further dislocation of the lateral column, leading to an ulceration of the lateral plantar foot. Additionally, ankle and hindfoot Charcot deformities can also occur, either as an isolated event or in combination, and can also lead to the development of an ulcer. Regardless of its location, ulcers often respond well to offloading of bony prominences and conservative management. When conservative management is unsuccessful, and if the deformities are unstable or non-braceable, the authors feel that they must then be addressed surgically in order to create a stable foot and ankle complex. The goal of the surgery is to create a stable or fused foot and ankle. Regardless of the location of any Charcot deformities, it is important to rule out any infective process that may have resulted from the previous ulceration. This chapter will hopefully provide useful information for the management of the Charcot foot and ankle using external fixation.

Indications and Preoperative Surgical Approach

As stated, the primary goal of surgery is to obtain a plantigrade foot that can be placed into an appropriate shoe and/or brace to minimize the risk for further breakdown or infection [7, 8]. Reconstruction of Charcot midfoot deformity is traditionally recommended during the coalescence or healing stage of the patient's arthropathy. Clear indications for surgery include an unstable deformity, a non-healing or infected ulcer, with or without the presence of osteomyelitis, a patient presenting with an equinus deformity, and a stable foot with a deformity that is at risk for ulceration in a shoe or brace.

One of the most challenging aspects in treating patients with Charcot arthropathy is in determining which patients are suitable candidates for reconstruction. One problem is in treating the neuropathic patient because the risks for complications are higher than for the non-neuropathic patient. A second problem is that these are often unhealthy patients presenting with significant comorbidities, such as cardiopulmonary disease, peripheral vascular disease, and immune dysfunction, all of which need to be addressed and optimized by the patient's medical specialists, including cardiology and endocrinology, before attempting any reconstruction. Lastly, the surgeon must be cognizant of the patient's psychosocial state and family support. Both the patient and their family should be educated about the risks and benefits of surgery, in addition to the importance and scope of the procedures needed for limb salvage [1, 4].

During the preoperative assessment, the clinician should obtain a thorough history that includes the duration and progression of the deformity, any history of ulceration or infections, and history of previous interventions, surgical or otherwise. The physical examination should include observing the patient's gait and stance, evaluating for any equinus, and evaluating the plantar surface of the foot to look for any areas of compromise that may lead to the development of skin breakdown or ulceration. Radiographic examination should consist of multi-planar foot and ankle weightbearing radiographs (anterior–posterior, lateral, and axial) to assess the foot and ankle alignment. These radiographic views aid in the planning that is needed to correct the deformity. Radiographs of the foot and ankle also allow the surgeon to determine the severity of the collapse and the amount of soft tissue edema that is present. If a proximal deformity is clinically observed, the radiographic evaluation should also include a standing radiograph of the patient's entire lower limb, which should include the pelvis, femur, and tibia, in order to assist in measuring lower extremity alignment, joint orientation angles, and limb length discrepancies [9]. The use of a computerized axial tomography (CT) scan is helpful for determining the quality and position of the bone. Also, a 3D reconstruction CT image provides beneficial information about morphology of the bone deformity. These radiographs are essential to accurately locate the center of rotation of angulation (CORA), or apex of the deformity for preoperative surgical planning [9]. Supplemental imaging studies such as bone scan or magnetic resonance imaging can also aid in the preoperative assessment and are helpful in identifying the extent of bone loss or infected bone segments [10]. Lastly, laboratory data, such as C-reactive protein or erythrocyte sedimentation rate, can be helpful in identifying osteomyelitis.

Surgical Management of the Patient

Various surgical methods have been described for the management of Charcot collapse. Large open incisions and wedge bone resections are typically performed to correct Charcot foot deformities [11, 12]. The disadvantages of this approach are the large amount of bone resection required, which shortens the foot, and the large incisions required to accomplish reduction. These approaches can also increase the rate of infection and create potential wound healing problems. We have developed minimally invasive techniques utilizing gradual distraction with realignment, in order to obtain and achieve an anatomic position of the foot and ankle during fusion of the Charcot joints. This technique also allows one to employ the use of an acute wedge resection, if necessary, in order to improve the alignment and attain a reduction and fusion of the Charcot foot and ankle. Deformity planning and principles are presented based on the authors' extensive experience in Charcot foot and ankle deformity correction. These general principles can hopefully help guide the surgeon when addressing the patient who presents with a Charcot deformity.

Management of the Soft Tissues

Before, during, and after treatment, one needs to respect the soft tissue envelope of the entire leg. During stage I of the arthropathy, the soft tissue swelling in the foot and ankle is extensive and should be managed before any surgical intervention is performed. During stages II or III, enough of the soft tissue edema and erythema has resolved that the clinician can really assess the foot and ankle to determine a treatment plan. During this preoperative planning, one should again carefully evaluate the foot and ankle and take notice of any ulceration that has developed, assess the stability of joints, identify the presence of any equinus deformity, and look for any bony prominences that may aid the surgeon in determining whether a conservative or surgical plan should be used. If conservative treatment is chosen, the goal is to maintain a closed, durable skin envelope that prevents ulcerations and infections. This approach consists of using protective shoes, braces, inserts, orthotics, and boots in any combination to assist in the offloading during weightbearing. For further information, please refer to Chap. 5. If surgery is contemplated, the dissections should consist of full thickness skin flaps that are raised in an atraumatic technique. Minimal incision techniques should be utilized when possible to minimize the soft tissue compromise in this unique patient population. Retraction of skin is limited, and should be used only when needed. Also, all postoperative edema must be controlled with elevation and appropriate fluid balance. At times admission into the hospital may be required to ensure strict elevation and medical fluid rebalancing.

Equinus Correction

Any equinus correction should be performed prior to the construction and application of the external fixation device. Charcot patients without an equinus deformity tend to fare better than those with a contracture. This is because an equinus deformity tends to produce ulceration over bony prominences on the plantar surface of the foot and can prevent one from obtaining an improved alignment of the foot and ankle. For these patients, a tendo-Achilles lengthening is recommended. The lengthening is performed at a level based on the Silverskӧld test. A gastrosoleal recession, using either a Vulpius or Strayer procedure, is preferred over the use of a Hoke triple hemisection tenotomy, because it allows the patient to maintain push-off strength and decreases the risk of a calcaneus gait. A gastrocnemius recession, using either a Baumann or Silverskӧld, is performed as an alternative if an isolated gastrocnemius equinus is present or if the patients possess a poor distal soft tissue envelope [13]. Alternatively, a gradual correction of the equinus can also be obtained using external fixation via gradual soft tissue distraction. This is performed by placing a hinged external fixator along Inman's axis of the ankle joint or by using a Taylor Spatial Frame to gradually correct the equinus, which typically is done in combination with the Charcot reconstruction procedure.

External Fixation Advantages

External fixation has many advantages when managing a Charcot foot or ankle deformity. First, its application is minimally invasive but the correction of deformity can be extensive. Second, because the correction can be obtained by gradual distraction, it can be used with or without the use of an adjunctive, limited open technique. Third, in cases of acute deformity correction, the external fixation allows for fine-tuning of residual deformity outside the operating room. In contrast, patients treated with internal fixation require that a precise correction of the deformity be obtained at the time of surgery, which cannot be altered during the postoperative period. Fourth, external fixation constructs allow for immediate weightbearing with an assistive device during the postoperative course. The use of early weightbearing can lessen disuse osteoporosis and minimize contralateral limb overload, which is typical in the Charcot patient. Fifth, the use of external fixation may allow for access to the soft tissues for wound care that is often utilized during treatment of osteomyelitis. Lastly, fine wire fixation avoids placing large implants through the bone, which can lead to stress risers or iatrogenic fractures.

External Fixation Disadvantages

The disadvantages of external fixation include the need for special surgical expertise required for construction. Second, pin site infection is a common complication, but this can often be handled with oral antibiotics. Third, failure of fixation can occur through the wire, ring, or half pin resulting in breakage or deflection. This can result in destabilization of the external fixation. Lastly, external fixation treatment may have to be left on for long periods of time to ensure complete osseous healing has occurred. This can result in loosening of wires and half pins. Although complications are seen with the use of any surgical approach, most complications using external fixation are minor, when recognized in a timely manner, and can be addressed non-operatively. Typically, when operative intervention is required, the external fixation can be left in position while the complication is addressed [14].

Construction of Stable External Fixation

Charcot neuropathic patients often present with one or more of the following problems: decreased healing potential, poor bone quality, obesity, altered osseous alignment, inability to maintain a non-weightbearing gait, vascular problems, lower extremity edema, and may present with ulcers, infections, or osteomyelitis, either as isolated problems or in any combination. Thus, constructing a stable and sustainable external fixation is a challenge. In order to obtain a rigid construct, one often needs to construct ring fixation blocks, and then place them on each side of the Charcot joint. A ring fixation block consists of two circular rings that are connected together using 4 or 5 threaded rods, telescoping rods, or sockets. The size or span of a ring fixation block can be the entire length of the tibia (150–250 mm threaded rods connecting the tibial rings) or can be only as high as the foot (40–60 mm sockets connecting the foot rings). The ring fixation block is then connected to the bone with at least four smooth wires and/or half pins. Half pins are reserved only for the tibia and in the Charcot patient the authors recommend using a 6 mm diameter half pin. In addition, the number of connections to the bone should be greater than what is generally used to manage the non-neuropathic patient, thus in general we add an additional point of fixation (half pin or smooth wire) per ring. When selecting rings to construct the fixation block, it is important that the ring size selected is able to accommodate any increased postoperative edema. Typically, full rings are preferred over 2nd/3rd rings because of the increased strength. Also rings that are one size larger than the ones used on a non-neuropathic patient are recommended so as to accommodate for postoperative leg swelling. Thus, normally the author's two fingers distance circumferentially between the ring and the patient's skin in normal patients. We use three fingers for the neuropathic population. The authors prefer the full Taylor Spatial rings (made of aluminum) for the leg (155–230 mm) and long foot closed rings completed with half rings for the foot (155–180 mm). The authors do not use composite rings (carbon fiber) as we feel these have less strength. A large span of tibial fixation is required to increase the stability. Any postsurgical tibial fractures have been noted by the authors to occur just proximal or at the proximal fixation point of the frame, thus we typically span most of the tibia. (see Fig. 13.3). The wires and half pins should be placed as close as possible to the ring fixation block to decrease cantilever (loading) of the bone. A foot block or "bumper" is two completed foot rings connected with sockets or threaded rods. The foot block (two completed foot rings) holds all foot, digital, and talar wires as well as it provides a walking surface by the addition of a bolted on cast shoe with the upper portion of the cast shoe cut off (Fig. 13.3c). This provides increased stability and protects the digits from accidental injury during the external fixation treatment period. The authors do not recommend half pins in the foot for neuropathic patients as the cortical bone in the foot is thin. In addition, we typically avoid the use of olive wires unless necessary for a dynamic correction. Olive wires create a periosteal reaction which can lead to pin site infection. The authors' recommend at least two points of fixation per bone segment with maximum obliquity of the two 1.8 mm Ilizarov wires, to ensure stability without the use of olive wires.

The ring foot block should be mounted parallel to the sole of the foot by using two crossed calcaneal wires: one perpendicular wire below the ring, from medial to lateral, and one obliquely placed wire above the ring, also placed medial to lateral. The calcaneal wires should be started medial and posterior to the lateral plantar nerve and medial to the Achilles tendon insertion. Tensioning on the two calcaneal wires should be approximately 110 mmHg using the tensioning device. In the midfoot, one wire is inserted across the cuneiform cuboid level and is tensioned (110 mmHg) and fixed. Next, two smooth wires are inserted into the talus. One is placed medial to lateral, through the talar neck, and the other from anteromedial in the neck of the talus to posterolateral to the Achilles tendon. The position of the wires should be monitored with fluoroscopy to make sure they do not enter the subtalar or ankle joints. The two wires are connected to the foot ring and tensioned (90 mmHg). Additional midfoot, metatarsals, and digital smooth wires (1.8 mm) are inserted as needed.

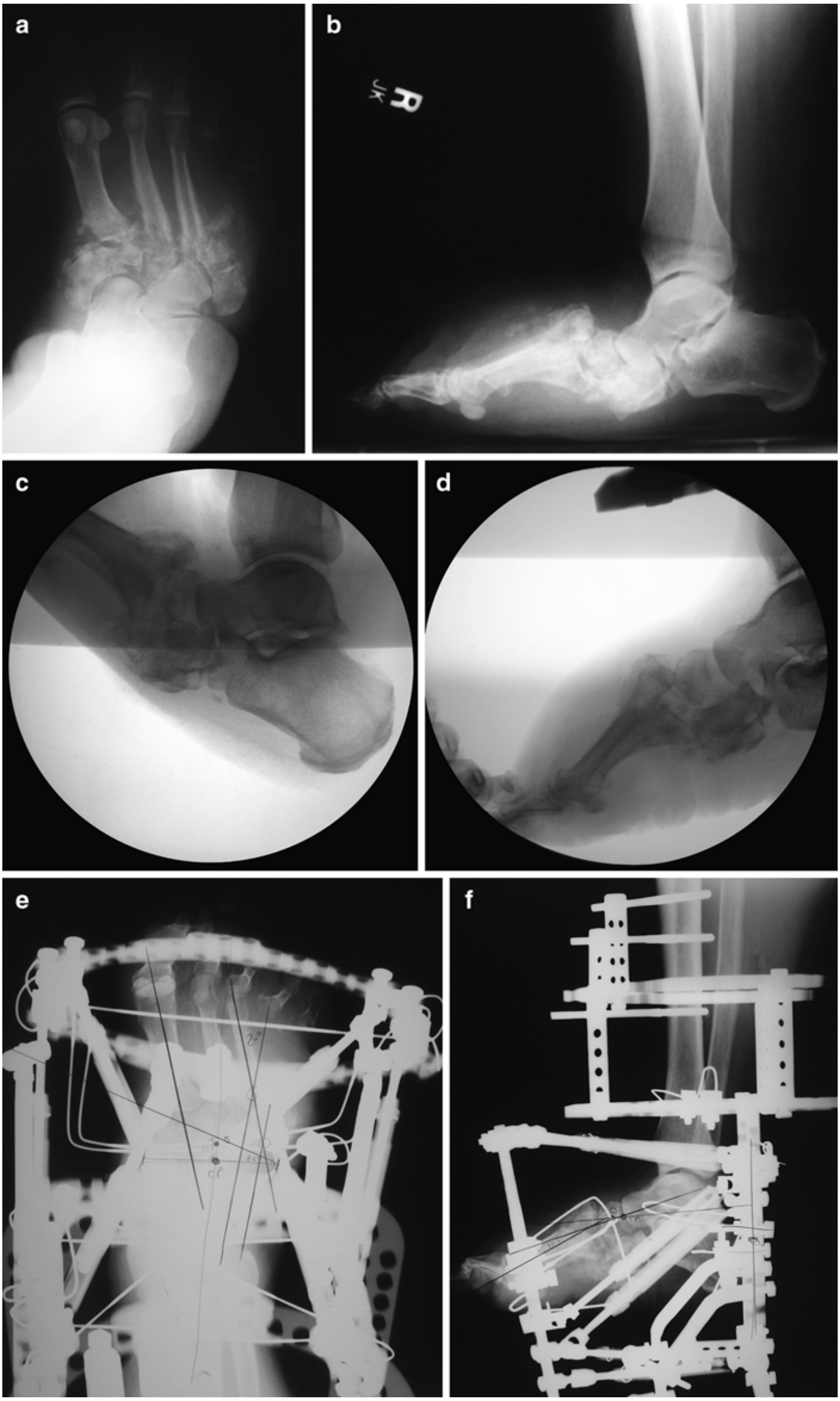

Fig. 13.1 (**a**) Anteroposterior radiograph view of a patient with midfoot Charcot neuroarthropathy deformity (Eichenholtz stage II, unstable) who also presented with a superficial plantar medial ulceration and previous resection of the 4th and 5th metatarsals. X-ray shows midfoot adduction deformity. (**b**) Lateral radiographic view shows rocker bottom and equinus deformities. Note the dorsal displacement of the forefoot and the break in Meary's

Fig. 13.1 (continued) angle. (**c**) The lateral fluoroscopic view image confirming instability of the midfoot Charcot demonstrating forefoot dorsiflexion. (**d**) The lateral fluoroscopic view demonstrating instability of the midfoot with significant forefoot plantarflexion. (**e**) Immediate postoperative anteroposterior radiographic view demonstrating midfoot adduction (*black lines*). Stirrup wires (90° bent wires that are not tensioned) are placed adjacent to the region of distraction and realignment (midfoot). (**f**) Immediate postoperative lateral radiographic view demonstrating some plantarflexion of the forefoot. The stirrup wires (90° bent wires that are not tensioned) are placed adjacent to the region of distraction and realignment (midfoot). (**g**) Clinical photograph demonstrating an applied Taylor spatial frame (forefoot 6×6 butt) applied. Note the delta configuration of the tibial half pins and the build out area of the distal foot ring in order to allow for soft tissue clearance. (**h**) A clinical lateral photograph shows the Taylor spatial frame (forefoot 6×6 butt) applied. Note the stirrup wires adjacent to the distraction region (midfoot). (**i**) Lateral radiographic view in which gradual Taylor spatial frame correction showing a near normal or zero Meary's angle. At this time the foot ulcer healed and the foot is correctly positioned. (**j**) After removal of the external fixator, a minimally invasive fusion of the midtarsal joint was performed. A weightbearing anteroposterior view radiograph shows three percutaneous intramedullary metatarsal screws that were inserted for stabilization of the fusion of the midtarsal joint. Note the improved anatomic reduction compared to the initial radiograph. (**k**) Lateral postoperative radiograph during weightbearing which shows a plantigrade foot with intact intramedullary metatarsal screws

When the frame is completed, there should be at least four connections between the tibial block and the attached foot block. Postoperatively, the authors prefer using prefabricated Ilizarov sponges on all half pins and smooth wires. These sponges are changed when soiled but maintained until the patient showers. Patients can shower but no soaking of the extremity is allowed until after the skin incisions heal, which is typically at 3–4 weeks post surgery. Every day or every other day patients are instructed to shower with antibacterial soap. Other than showering, no daily pin care is instructed. If crusting on the pins is noted, the patient is instructed to clean off the pin(s) using a plain saline solution and a cotton tipped applicator. In addition, the authors also recommend that patients keep the external fixation covered with an ace wrap or some kind of cover to decrease the risk of external environment influence.

Rehabilitation

Before, during, and after any treatment, the patient, family, and friends should be educated and recruited to assist in the success of healing. Frequent follow-up visits and close home or rehab monitoring are essential for a successful outcome. In addition, the surgeon's support staff must be well versed on the protocols and easily reachable by the patient. When an issue arises in this patient population, prompt action is required.

The external fixator is typically left on for 3–4 months. Patients are instructed to begin with immediate 50 % weightbearing with an assistive device (crutches or walker). Patients are seen in the clinic weekly or biweekly and radiographs are taken at this time to determine the time for removal of external fixation. Advanced imaging, using a CT scan, is considered to evaluate the fusion mass when visualization of the osteotomy/fusion is difficult via radiograph or to assess bone healing prior to removal of the external fixation. After removal of the external fixation in the operating room, the patient is then placed into a cam walking boot for 1 month. The patient is then transitioned into a custom molded ankle foot orthosis with extra depth shoes or Charcot Restraint Orthotic Walker (CROW) for 8–12 months following frame removal. After this time period and radiographic proof of mature bone healing, the patient is placed into an extra depth or molded shoes with custom multilayer inserts.

Management of Specific Arthropathies

Treatment of Acute Charcot (Eichenholtz Stage 1)

Static ring external fixation has been used early, in place of a cast, to offload the Charcot event and prevent further subluxations and dislocations from occurring [15]. The wires/pins are placed in areas that avoid the region of the Charcot arthropathy. Application of the external fixator during stage I has some advantages. It offloads pressure over any ulcerations, it helps maintain an anatomic position of the remaining bony anatomy, it allows for early partial weightbearing, it may provide quicker healing of the acute Charcot event, and it provides for an easier reconstruction if the Charcot event progresses into stage 2. However, the use of this technique during this stage of arthropathy should be undertaken with caution as the patient is metabolically compromised and the longevity of the acute Charcot event is unknown. The authors recommend application of external fixation for stabilization at the end of the acute phase.

Acute Midfoot Correction with External Fixation

A nonmobile malunited Charcot joint will often need the addition of an osteotomy to obtain correction of the deformity. In contrast, the mobile Charcot joint will need anatomic reduction and formal fusion. Factors such as poor vascularity, reduced bone mineral density, due to long periods of strict non-weightbearing, and impaired nutrition all decrease the patient's ability to heal [16–18]. Although internal fixation can be used, it is often used to add stability and to augment the external fixation.

An acute correction can be obtained by performing a wedge resection at the apex of the deformity. The correction shortens the skeleton, allows the bony segments to be realigned and decreases tension on the soft tissue structures to allow for easier wound approximation. The approach is made through medial and/or lateral incisions utilizing full thickness flaps. The type of incision varies depending on the type of deformity and the presence of an ulceration. Medial/lateral vertical incision are used when foot shortening osteotomies are employed and a plantar transverse incision is utilized when a large plantar ulcer is present with a rocker bottom foot deformity. Using fluoroscopy, Kirschner (K-wires) wires are inserted from medial to lateral to act as cutting guides for the biplanar wedge resection. See Glossary for description. The resection is performed with a combination of a large saw and sharp osteotomes, with care taken to protect dorsal and plantar neurovascular structures. The resected bone can be used for grafting if viable or allograft stem cells can be added for improved osseous consolidation. Provisional fixation is obtained using axially placed 2.0 mm K-wires or larger Steinman pins. Layered skin closure is performed and a drain is utilized as needed.

A static circular external fixator is then applied using a tibial ring fixation block, with at least 3 points of fixation per ring (combination of 1.8 mm wires and 6 mm half pins). The foot ring block is then constructed and mounted parallel to the sole of the foot, by placing two 1.8 mm wires into the calcaneus and two 1.8 mm wires in the talus (these wires are inserted medial to lateral). Next, a 1.8 mm wire is inserted distal to the wedge resection and is tensioned as a bent wire, by walking the wire onto the foot ring posteriorly by one or two holes from where it was inserted and exited the skin. This bent wire tension technique allows for compression of the midfoot with the wires that were placed in the talus and calcaneus. Two additional tensioned metatarsal wires are inserted for additional stability, one placed from medial to lateral and capturing the first and second metatarsals and one placed from lateral to medial from the fifth through second metatarsals. In cases of mobile severe Charcot deformity, where osseous and soft tissue problems prevent acute correction, the authors will also utilize gradual distraction with the external fixation to correct any residual deformities.

Gradual Midfoot Correction with External Fixation

This minimally invasive 2-stage approach, to correct a midfoot Charcot deformity, was initially described by Lamm and Paley [19]. It can be used for both rigid or mobile deformities and utilizes gradual correction of the deformity through soft tissue distraction utilizing external fixation. It is then followed with either static compression, applied through the external fixator, or by removing the external fixation and achieving an arthrodesis using percutaneously placed intramedullary foot fixation (IMFF) [20]. These two approaches obtain and maintain anatomic realignment, avoid large incisions, limit neurovascular compromise, preserve foot length, and reduce the risk of infection.

The first stage consists of gradual deformity correction achieved by ligamentotaxis. The majority of Charcot midfoot deformities can undergo distraction without the need for an osteotomy to realign the pedal architecture. However, a stable or coalesced Charcot deformity may require an osteotomy before gradual correction can take place. The authors perform this osteotomy by using a Gigli saw that is placed percutaneously through the midfoot. Of note is that no bone is removed, just the osteotomy is performed. When the midfoot is mobile, no osteotomy or open surgery is required other than a posterior muscle group Achilles lengthening prior to application of the external fixation. The authors prefer using a Taylor Spatial Frame (TSF) in which a 6×6 butt frame is constructed and applied to the foot. The butt portion of the frame is where the tibial and calcaneal rings meet at a 90° attachment. A second forefoot ring is mounted to the forefoot and the 6 struts are placed between the butt ring (calcaneal and tibia) and the forefoot ring. A reference ring must be chosen by the surgeon from the computer based software analysis, which can either be the proximal or distal ring. A second more proximal tibial ring can be applied for additional stability. It is essential to first fix the hindfoot and the ankle in neutral within the TSF. The forefoot is then fixed to a distal foot ring. Finally, the TSF struts are applied and final radiographs are obtained orthogonal to the reference ring. The reference ring radiographs are significant because they allow one to obtain accurate measurements postoperatively that will then allow the surgeon to enter it into the computer web-based program for deformity correction. Gradual distraction of the forefoot on the fixed hindfoot is performed using the TSF to realign the pedal anatomy. This first stage should be accomplished within 2–3 weeks or less [19]. During this phase of treatment the patient is instructed to be non-weightbearing or heel touch down only, as the forefoot ring is moving to correct the deformity.

The second phase of the correction consists of performing a minimally invasive arthrodesis of the affected joints. Minimally invasive arthrodesis is easily preformed because the Charcot joint(s) are already distracted. The arthrodesis is achieved by making small transverse incisions (2–3 cm in length) over the affected joint(s). An important step during this part of the procedure is to first remove any remaining articular cartilage and then prepare the joints for an arthrodesis. At this time, the Charcot midfoot can be stabilized using some kind of internal fixation or the external fixation can be adjusted to perform static compression of the midfoot, adjusting the external fixation to allow for partial weightbearing.

When using internal fixation, the external fixation is first removed. Under fluoroscopic guidance, minimally invasive arthrodesis is performed and then guidewires for large-diameter cannulated screws are inserted retrograde and percutaneously through the plantar skin into the metatarsal head by dorsiflexing the metatarsophalangeal joint. The medial column screw is advanced into the talus and the lateral column screw is directed into the calcaneus. The authors prefer using three large-diameter cannulated (7.0 or 8.0 mm) intramedullary screws inserted through the metatarsals. Predrilling or reaming is performed prior to screw insertion. Typically a first, second, and fourth metatarsal screw are placed. The medial and lateral column screws are partially threaded to allow for compression of the arthrodesis site and the centrally placed screw (second metatarsal) is fully threaded and is used for stabilization. These screws span the entire length of the metatarsals into the calcaneus and talus, respectively. The minimally invasive incisions are then closed, and a well-padded splint is applied. Before hospital discharge, the authors remove the patient's operative splint and apply a short leg cast. A non-weight-bearing short leg cast is maintained for 2–3 months, and then gradual progression to weightbearing in a cam boot is achieved. The entire treatment is completed in 4–5 months. The advantages of using external fixation combined with intramedullary fixation include obtaining an anatomic realignment of the foot, using a minimally invasive fixation technique, obtaining formal multiple joint fusions, adjacent joint fixation beyond the level of Charcot collapse, providing rigid interosseous fixation, preservation of foot length, and combining it with external fixation when necessary [19].

Alternatively, the external fixation can be used alone to obtain an arthrodesis of the midfoot. In this approach, medial and/or lateral incisions are still utilized to prepare the joints for a formal fusion. After skin closure, the external fixation is adjusted, adding a U-foot ring, for compression of the formal fusion via the bent wire technique. In addition, an external fixation walking ring is placed to allow for partial weightbearing with an assistive device (crutches/walker). (Figs. 13.1 and 13.2).

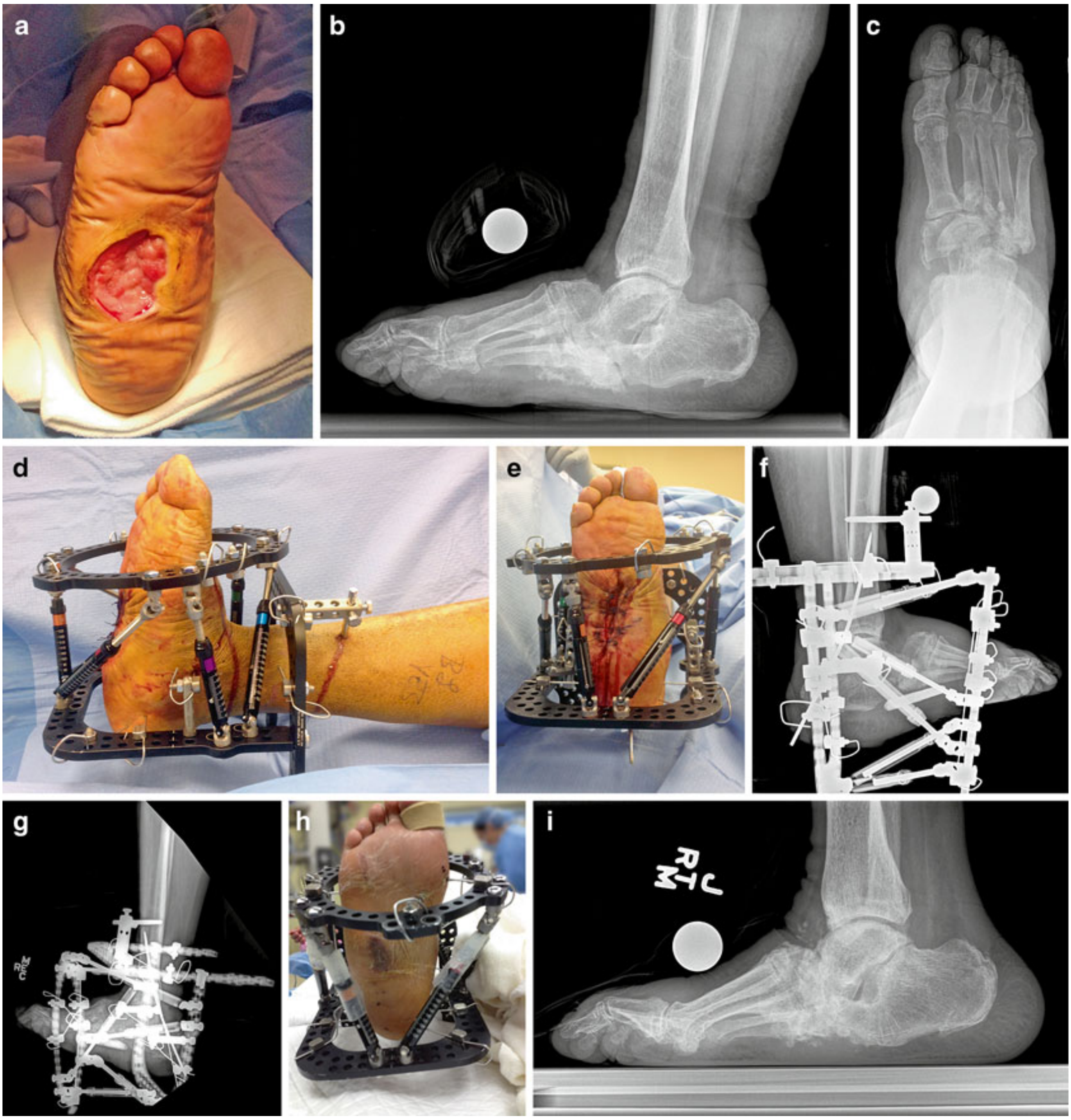

Fig. 13.2 (**a**) A patient who presented with a midfoot Charcot neuroarthropathy deformity (Eichenholtz stage II, unstable) along with a large plantar central ulceration. (**b**) Lateral weightbearing radiograph demonstrating midfoot collapse and equinus. (**c**) Anteroposterior weightbearing radiograph demonstrating a midtarsal Charcot deformity with superimposition of the tarsal bones and a varus deformity, indicating shortening of the foot. (**d**) Immediate postoperative lateral clinical picture shows application of Taylor Spatial Frame (6 × 6 butt) for gradual distraction of the midfoot Charcot dislocation. There were no open interventions other than an Achilles tendon lengthening. (**e**) Clinical image after acute excision of the plantar ulceration and closure were performed. (**f**) Immediate postoperative lateral radiograph shows application of Taylor Spatial Frame (Butt frame) for gradual distraction of the midfoot Charcot dislocation. Note that after the Achilles tendon lengthening an extra-articular temporary large diameter pin is traversing the calcaneus and tibia posterior and crosses the ankle and subtalar joints. (**g**) Postoperative lateral view after 2 weeks of gradual distraction of the midfoot with Taylor Spatial Frame. Note the realignment of the forefoot in relation to the hindfoot. A second minimally invasive joint fusion surgery was performed to achieve arthrodesis using external fixation compression. The compression frame was maintained for 2.5 months and the external fixation was then converted to a weightbearing frame with attachment of the walking ring. (**h**) A clinical image of the plantar surface of the foot at the time of external fixation removal, of note the plantar ulceration has completely healed. (**i**) The final 1 year postoperative lateral view weightbearing radiograph shows a stable midfoot fusion and a plantigrade foot

Acute Hindfoot/Ankle Correction with External Fixation

The authors feel that when a severe deformity and bone loss are present in the subtalar and ankle joints, the use of external fixation can be a viable fixation modality. The presence of the arthropathy often affects the bone substance of the calcaneus or talus and may make it more difficult to obtain a successful fusion when using internal fixation. In addition, the use of screws, plates, or intramedullary nailing has a disadvantage in that it can create more soft tissue dissection, result in less bone to bone contact at the fusion site, and produce limit stability in osteoporotic bone. The authors also feel that external fixation with compression of the tibiotalocalcaneal or calcaneal tibial fusion can provide stability and allow maximal bone to bone contact for healing. In addition, the external fixation can be adjusted during the postoperative course for added compression while the patient is allowed to be partial weightbearing. For the management of these patients, the authors typically employ a lateral transverse incision, at the level of the dorsal calcaneus, as seen on a lateral fluoroscopy image, to allow ease of skin closure that will occur due to the shortening of the osseous segments.

A stable external fixation construct is constructed. A tibial ring block and foot ring block are mounted and three threaded rods are placed between the ring blocks to allow for compression. As mentioned previously, two wires are placed in each bone segment (talus and calcaneus) and inserted with as much obliquity as possible. When performing a tibiotalarcalcaneal fusion, the subtalar joint is compressed first. To do this, the authors first apply the tibia fixation block, then apply to foot ring to the calcaneus with the two aforementioned tensioned calcaneal wires. Two talar wires are then inserted and, when attaching them to the foot ring, are arched down (insert them into a hole one closer to the foot ring than would be typical). By arching the talar wires down to the foot ring (tensioning the talar wires in such a way that forces the wire to straighten), this will compress the subtalar joint as the two calcaneal wires are already affixed to the foot ring. After subtalar compression has been achieved, the foot block is then compressed proximal against the tibial block by shortening the threaded rods between the tibial and foot ring fixation blocks.

For a tibial calcaneal fusion, three calcaneal wires are placed, the medial to lateral wire, posterior-medial to anterior-lateral oblique wire, and an axial anterior to posterior wire from the third metatarsal to the calcaneus. After the ankle and hindfoot are realigned, the external fixation is left in position for approximately 3–4 months to maintain the correction and obtain a fusion. The greatest challenge in these patients is the hypermobility of the midfoot that can occur following the hindfoot fusion. After removing the external fixation, a CROW boot is maintained for at least one year and then consideration is given to placing the patient into an Ankle Foot Orthosis that is combined with a custom shoe and insert (Fig. 13.3).

Complications, Obstacles, and Problems

The authors have published a standardized classification of difficulties that can arise during external fixation treatment. This classification differentiates problems, obstacles, and complications when utilizing external fixation [14] on the premise that not all adverse results are true complications that affect the final outcome. Furthermore, the authors feel that the problems and obstacles that arise may simply be hurdles to complete a successful treatment.

Adverse results can occur intraoperatively, perioperatively, or postoperatively. We have classified adverse results (undesirable outcomes) that occurred during treatment into problems, obstacles, and complications. Adverse results that can occur during surgical management include fixation failure, nonunion, vascular insult, pin site infections (superficial or deep), swelling, and delayed bone or soft tissue healing.

Problems are defined as anticipated adverse results that arise from the treatment but resolve without surgical intervention by the end of treatment.

Fig. 13.3 (**a**) The lateral weightbearing radiograph demonstrating an unstable peritalar Charcot deformity. (**b**) A Saltzman weightbearing radiograph shows a varus and medial displaced left hindfoot. Note the enlarged soft tissue envelope of the left ankle and leg as compared to the right. (**c**) Postoperative lateral weightbearing clinical image shows a reinforced tibial and foot block with a static external fixator. Note the transverse lateral ankle incision, which provided for an ease of arthrodesis and closure. (**d**) Postoperative lateral weightbearing radiograph shows stable tibial and foot block external fixator for calcaneal tibial fusion. (**e**) The Saltzman weightbearing axial radiograph now shows a vertical and centralized hindfoot beneath the tibia. (**f**) A 3-year postoperative weightbearing lateral view radiograph shows consolidation of the calcaneal tibial fusion with a plantigrade foot. (**g**) A clinical anterior weightbearing view at 3 years postoperatively demonstrating good alignment. (**h**) A clinical weightbearing lateral view photo 3 years postoperatively. Note the well-healed lateral incision. (**i**) A clinical plantar view photo 3 years postoperatively demonstrating no plantar ulceration

Obstacles are described as anticipated adverse results that require surgical intervention but resolve by the end of treatment.

Complications are identified as local or systemic adverse results whereby their associated sequelae remain unresolved at the end of treatment. Not all complications interfere with the original goals of treatment. Complications are further subdivided into minor or major. Minor complications are adverse results that remain unresolved at the end of treatment but are considered to be of little significance and do not interfere with the initial goals of surgery. Major complications are adverse results that remain unresolved by the end of treatment and interfere with the original goals of treatment. Thus, an understanding of these problems, obstacles, and complications is essential for success.

One other problem that the authors have also observed is the reoccurrence of an equinus deformity that can occur months after reconstructive surgery. To address this problem in a timely manner, we routinely recommend checking the patient to make sure that no equinus has reoccurred. The authors feel that if there is no residual equinus component, there is less likelihood of collapse that can result in ulceration in the future. In the authors experience even if midfoot collapse reoccurs (due to broken hardware, partial/incomplete fusion, pseudoarthrosis), as long as the foot functions as a unit and has adequate ankle dorsiflexion, then the chances for recurrent ulceration decrease.

Conclusion

The Charcot foot and ankle are complex and challenging deformities to treat. By observing the basic principles of use, understanding when to utilize external fixation, learning how to construct a stable frame, and where to apply the external fixation is paramount to obtaining a good outcome. External fixation for treatment of Charcot arthropathy is not recommended for the inexperienced surgeon. To obtain adequate knowledge for use with this device may require going to courses, lectures, seminars, obtaining books and reading materials on this subject, visiting and observing these approaches at centers which commonly employ the use of external fixation, and if possible obtaining personal instruction by an experienced Ilizarov surgeon. Reconstruction of Charcot deformities has relatively high complication rates; however, complications can be minimized by proper patient selection, accurate preoperative evaluation of deformity, use of sound surgical principles, and proper postoperative care. Obtaining an osseous union is the standout factor for describing a successful surgical outcome. Although a pseudoarthrodesis or semi-stable union can be temporarily successful, the problem is that in the long run a re-ulceration is likely to occur. In the authors opinion, the use of external fixation may provide the only option for limb salvage. Although the method of reconstruction and the fixation utilized has a great influence on the success of the arthrodesis, the authors also feel that the health status of the host will ultimately determine a successful osseous union.

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