# The Charcot Foot

# 24

Naohiro Shibuya

## Introduction

Pathogenesis of neuroarthropathy is debatable. A number of theories have been proposed, but it is conceivable that sensorimotor along with autonomic neuropathy of any origin can potentially result in development of the disease. Although poliomyelitis, folate deficiency, spinal cord lesions, meningomyelocele, syringomyelia, leprosy, and peripheral nerve injuries are reported as causes of neuroarthropathy in the literature [1–7], most of the Charcot arthropathies in the foot and ankle manifest in a diabetic population [8, 9]. This may be due to the sequelae of diabetic neuroarthropathy being far more detrimental than those of nondiabetics.

In the lower limbs, development of micro- and macrovascular diseases, along with peripheral neuropathy, makes wound and bone healings extremely difficult [10, 11]. This results in the incidence of amputation being more than ten times higher in diabetics than in nondiabetics [12, 13]. Diabetic patients with Charcot disease can also be less compliant, more obese and more immunocompromised; and these characteristics can complicate the pre- and postoperative managements. While Addolorato et al. showed significantly lower body mass index in alcoholics comparing to social drinkers [14], Pinzur et al. observed a large proportion of obesity in patients with midfoot Charcot deformity [15].

Due to these reasons, people with symptomatic neuroarthropathy are categorized in one of the highest-risk groups that foot and ankle surgeons can encounter. Surgeons who treat these patients therefore need to be familiar with common complications associated with neuropathy, noncompliance, obesity, poor glycemic control, and any other underlying medical and social conditions that are common in this population.

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## Indication for Procedure

Due to a high complication rate, indication of such reconstructive surgery, especially in revision surgery, should be carefully evaluated. While primary Charcot reconstruction is indicated in patients who can otherwise lose his/her limb, in a revision surgery one has to reconsider the benefit of amputation as well. Charcot arthropathy represents an end spectrum of the diabetic disease process along with cardiovascular, neurological, and immunological problems; therefore, even a perfectly executed reconstructive surgery may result in major complications. If a patient is doomed to fail reconstruction, primary amputation reduces patients' burden and healthcare cost significantly.

In the arena of vascular reconstruction in critical limb ischemia, there are guidelines to assist surgeons decide whether to salvage or amputate. These guidelines are based on numerous studies evaluating quality of life and cost effectiveness of amputation versus vascular reconstruction [16–27]. These guidelines are developed to reduce futile reconstructions.

Trans-Atlantic Inter-Society Consensus have suggested that primary amputation in critical limb ischemia is indicated when (1) it is non-reconstructable, (2) there is significant necrosis on weight-bearing surface, (3) there is flexion contracture of the leg, or (4) the patient is terminal ill/limited in life expectancy [28]. Further, European Consensus Document states, "a reconstructive procedure should be attempted if there is a 25% chance of saving a useful limb for more than one year" [29].

On the other hand, there is no consensus or guidelines for Charcot reconstructive surgery though these patients may be classified in the same health-risk category. The 5-year survival rates in these critical limb ischemia patients having a major amputation and Charcot patients are similar [30, 31].



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Lack of guidelines in Charcot reconstruction therefore demands foot and ankle surgeons to methodically evaluate the patients' medical and social conditions prior to considering extensive reconstructive works. The surgeons need to be able to evaluate the patient's practicality to rehabilitate and likelihood of saving a functional limb for a decent period of time.

For example, high-risk patients, such as ones with end-stage renal disease (ESRD) on dialysis, are known to have poor prognosis. According to US renal data system, life expectancy of dialysis patient between 65 to 69 years old is 3.2 years, and 2-year survival rate in those patients who undergo vascular reconstruction is approximately 50% [20–22, 32, 33]. When compared to a longitudinal study by Lavery et al. [34], the 2-year survival in those dialysis patients who underwent various lower extremity amputations was comparable or even superior. This may suggest that amputation may not necessary accelerate mortality in these high-risk patients.

As reconstruction requires substantial time to recover, it demands a considerable fraction of his/her remaining lifetime. These patients undergo burden of office visits and prolonged non-weight-bearing status, which may worsen their quality of life significantly. It should also be noted that a failed reconstruction resulting in amputation is significantly more debilitating to the patient when compared to primary amputation.

Therefore, only a small proportion of patients may truely benefit from these extensive procedures. These procedures may best benefit selected relatively young, compliant patients with longer remaining life expectancy, who is less likely to be deconditioned from a long recovery process, and also those who can improve underlying biology or medical conditions.

## Contraindications/Limitations

Because of the reasons indicated above, many patients who are in this category are poor candidates for surgical revisions. Therefore, risk factor assessment via evaluation of medical conditions, socioeconomic state, and psychology is necessary to avoid further complications. While many surgeons may be familiar with the medical-risk factors, the patient's socioeconomic state and psychology are often overlooked.

It can be impractical for some patients to stay off-weight-bearing completely, acquire an expensive brace, and obtain family support or even to make it to the postoperative office visits frequently. A surgeon needs to be an excellent social worker to understand every aspect of perioperative socioeconomic needs for the patients.

Similarly, psychology of the patient is very important when assessing these individuals. Compliance, expectations, and intelligence of the patient and availability of his/her family need to be evaluated thoroughly. It is not uncommon that the patient's initial office visit is the surgical consultation visit, as the referring physician may have already tried conservative measures. Therefore, the surgeon may spend a little time with the patient before scheduling for surgery.

Many of these patients can have a high hope and expectations. A full comprehension of the disease process, risks, and benefits of the surgical management, postoperative convalescence, and reasonable surgical outcomes may take a long time or even several office visits for those patients. During these visits, a surgeon may gain a better understanding of the patient's and his/her family's personality, perspective, intelligence level, and expectations.

There is overwhelming evidence that a high glycated hemoglobin level is associated with poor outcomes in foot and ankle surgery. Both wound and bone healings are independently associated with poor glycemic control [35–37]. Many use a cutoff level of 7% to categorize good versus poor surgical candidates, based on the American Diabetes Association (ADA) recommendation. The ADA recommendation is derived from several studies assessing intensive glycemic control therapy in reducing long-term complications associated with diabetes. However, under glycated hemoglobin of 7%, the benefits seem to diminish, and there is also a risk of adverse events including death, weight gain, and hypoglycemic episodes from a rapid drop in the glucose level.

However, what constitutes an "acceptable" or "ideal" glycated hemoglobin level for foot and ankle Charcot surgery is still unclear. An "acceptable" upper glycated hemoglobin limit for foot and ankle surgery can be interpreted as a level from where the rate of complication spikes significantly. Alternately, the "acceptable" cutoff line can be defined as the level at which the risks associated with surgery become greater than those associated with nonsurgical treatment. Regardless, the "acceptable" level may vary depending on the procedure. For example, incision and drainage for infection may have a higher "acceptable" glycated hemoglobin level than an elective reconstructive surgery.

Most studies in foot and ankle surgery to date are comparisons of glycated hemoglobin levels between groups with or without complications. As recommended by many, including the American Diabetes Association, glycated hemoglobin of 7% is known to be a relatively good reference point, at least in terms of general health. However, there are no Charcot-specific guidelines. Jupiter et al. have shown the trend in complication rate in accordance of perioperative glycated hemoglobin [36]. They have found that the rate of complication quickly elevates after approximately 7.4%. However, at this level the soft tissue complication rate was already over 20%.

Because the patients with a Charcot foot are high risk, modifiable factors should be optimized. Smoking and morbid obesity may be relative contraindications to some surgeons in non-Charcot elective surgeries. The adverse effects of these factors are accentuated when coexisting with other uncontrollable risk factors in Charcot patients.

There are many other medical factors in these high-risk patients that are considered contraindications for a surgical management. Those other medical factors will be discussed under each specific complication section.

## Technique Pearls and Pitfalls

Surgical management of Charcot foot is mostly presented in low-level studies [38]. The relative paucity of this group of patients precludes any well-controlled studies to show statistically meaningful results. Although there is no consensus on the "best" approach for primary Charcot reconstruction, some intraoperative factors are known to affect surgical outcomes. Avoiding complications is difficult in Charcot surgery since many variables besides surgical execution play a role in the poor outcomes. As mentioned earlier, underlying medical condition, psychology, and socioeconomic states of the patients are as or more important than surgical techniques themselves.

Midfoot Charcot deformity may be reconstructed with dorsal, planter, medial, lateral, or combination of those incisional approaches. Although most of these patients are insensate, a careful dissection is still paramount to preserve remaining neurological structures, as they are still important for bone and soft tissue metabolism for healing. Arthroscopic preparation of ankle or rearfoot joints or any other minimally invasive approach would also help increase the bone and wound healing potential in these high-risk patients.

Soft tissue dissection is followed by resection of necrotic or infected bone. Similar to revision surgery in nonunion patients, good bleeding cancellous bone is needed for a successful fusion. Aggressive resection is often needed to achieve this goal. It should be noted that the density of the Charcot bone might not necessarily be lower than a healthy bone. In fact, the density of chronic neuroarthropathic bone can be increased as the quality of trabecular pattern worsens [39]. Therefore, after resection of the brittle soft bone, one has to also make sure that sclerotic, chronic neuropathic bone margin is also resected. Preoperative radiographic examinations, such as plain X-rays or MRI can reveal the extent of infected or necrotic bone (Fig. 24.1).

Aggressive resection of the necrotic bone can result in shortening of the foot. Though it may not be visually appealing to the patient, biomechanically this can be advantageous. A shortened foot results in a smaller moment lever arm during the stance to propulsion phases of the gait and reduces the forefoot pressure. Though the maximum involvement in neuroarthropathy may be in the midfoot, Armstrong et al. have found that the peak pressure was in the forefoot [40]; therefore, reducing this pressure by shortening the foot may be biomechanically beneficial. It may also indirectly reduce the mechanical stress applied to the midfoot, contributing to the survival of the internal fixation devices. Though the patient needs to be aware of this potential shortening of the foot, because the reconstruction straightens the overlapped midfoot, the foot may not appear significantly shorter than preoperative length to many patients (Fig. 24.2). The patients should however be notified about digital deformities or non-purchasing digits that it may cause (Fig. 24.3).

It is not advisable to use nonviable osteobiologics to replace the necrotic Charcot bone. Not only the evidence for use of such products are lacking, replacing such a large defect and to achieve stable union is difficult even in healthy individuals. Because pathophysiology of neuroarthropathy involves inhibited anti-inflammatory process (Fig. 24.4), introduction of reactive foreign materials, excessive inflammatory cytokines, and growth factors may result in a vicious, uncontrolled, inflammatory cycle.

a b

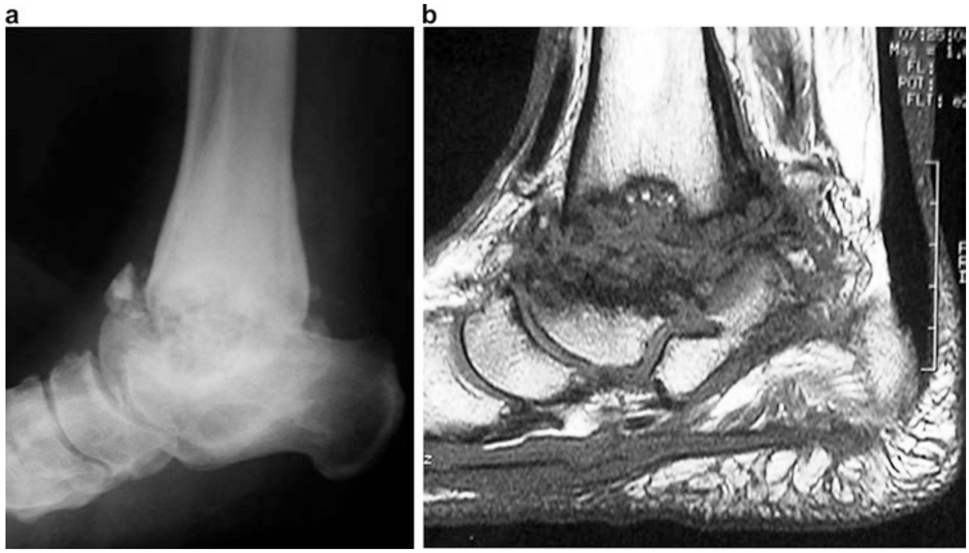


**Fig. 24.1** While the extent of the diseased bone may not be clear in a plain X-ray, it may be clear in an MRI

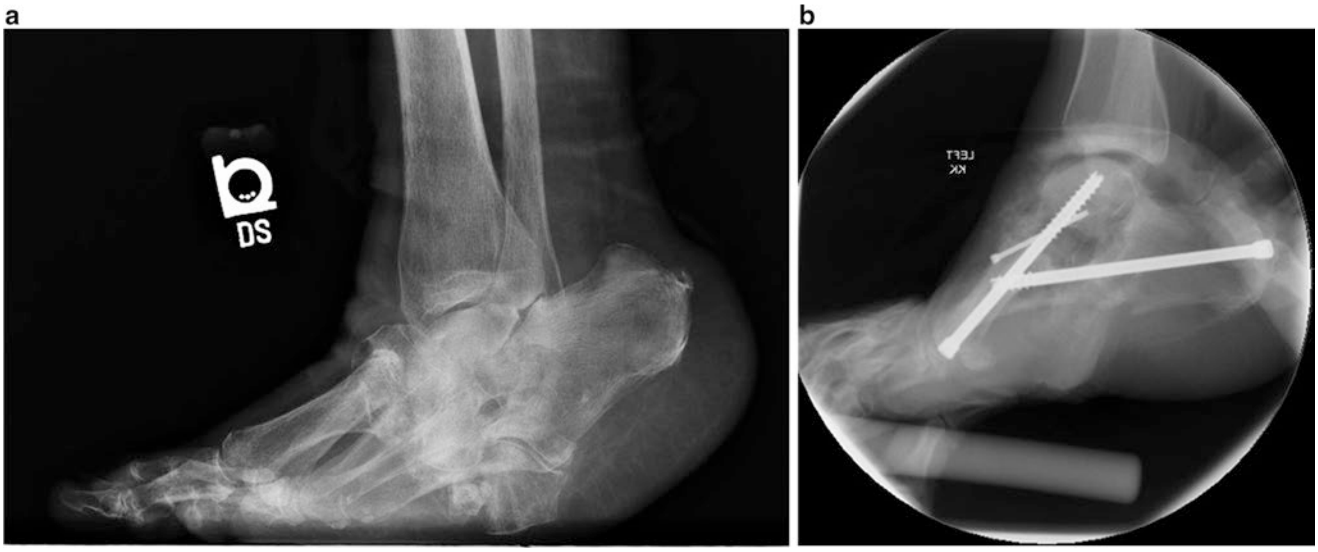


**Fig. 24.2** (**a**) A Charcot foot may already appear shortened due to the overlapping of the midfoot. (**b**) Aggressive resection of the diseased midfoot bones may not necessarily result in a shorter appearing foot

**Fig. 24.3** Shortening of the midfoot can lead to non-purchasing digits due to loss of extensor and flexor stabilization

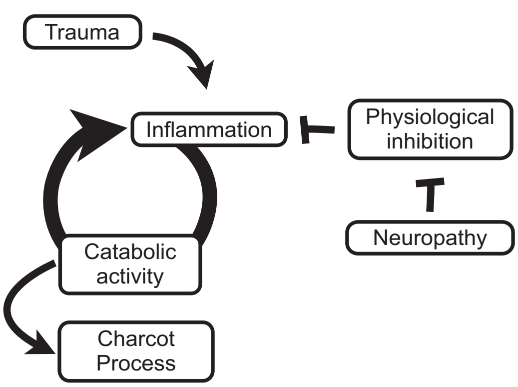



**Fig. 24.4** Inhibition of the physiological anti-inflammatory feedback system due to neuropathy can result in excessive catabolic activities and a Charcot process

A minimal amount of nonreactive material may be indicated to fill a small void given that most of the arthrodesis sites are in close proximity. Some mesenchymal cell-based

**Fig. 24.5** Resection of cuneiforms and distal cuboid resulting in the fifth metatarsal not articulating with the rearfoot when the medial column is aligned due to the wider forefoot to the narrower rearfoot

products are thought to have anti-inflammatory effect in the local tissue via paracrine signaling [41–43] though this phenomenon is yet to be tested in a Charcot clinical study. Research in this area is lacking understandably due to its relatively low prevalence of the disease.

Another caveat to aggressive resection of the necrotic tissue is that it often results in mismatching of the forefoot to the rearfoot. Because forefoot is wider than the rearfoot, it may not be possible to align both medial and lateral columns onto the remaining rearfoot (Fig. 24.5). If needs to be chosen, aligning the medial column is far more critical than the lateral column. It is advisable to align the first ray with the long axis of the talus even though the lateral column alignment may be compromised.

When resecting the midfoot, it is also important to avoid severe abduction or adduction. The midfoot often needs to be resected uniformly across from medial to lateral even when Charcot is affecting one side. When neuroarthropathy affects mainly the medial side and only the medial necrotic bone is aggressively resected, the significant shortening of the medial column can result in excessive forefoot adduction. This is biomechanically intolerable; therefore, resection of the healthy lateral column may be necessary to achieve balanced medial and lateral columns.

After arthrodesis sites are prepared, the forefoot is impacted onto the rearfoot and fixations are applied. Though it is a surgeon's preference, some fundamental of fixation should be reviewed.

Many of the screws are positioning and beaming in nature in Charcot reconstruction rather than compression. It is more critical for the screws to be strong and resistant to bending. Unlike elective arthrodesis surgeries in non-neuroarthropathic patients, bone healing is expected to be prolonged, and patients are less likely to be able to off-load the operative foot effectively. It should be noted that stainless steel, solid screws are far stronger than titanium and cannulated screws given the same size. Additionally, the core diameter, rather than the outer diameter, of the screw determines the overall shearing and bending resistance.

One also needs to remember that fatigue property and ductility of the screws play a role in the long-term stability. Because of the cold-working process in stainless steel, the ductility is significantly compromised when compared to titanium. Therefore, once the metal is bent or contoured, it becomes more brittle. This concept is particularly important when considering plate fixation.

Pullout strength is significantly better with titanium since the friction is greater due to its osseointegration. Though it is a useful property for a rigid, long-term fixation, removal of such screws is more difficult. Biocompatibility is superior with titanium, yet that of stainless steel is still sufficient, and nickel allergy is rare. When a patient needs an MRI in the future, titanium avoids signal void effects.

For plate fixation, abovementioned metallurgy is still relevant. The plate fixation, however, requires more molding to a contour of the osseous structures; therefore, ductility of the metal cannot be over-emphasized.

External fixation has been popular in Charcot reconstruction [44–47]. It can provide extra stability, dynamic compression if necessary, potential earlier weight-bearing, postoperative deformity correction, and bypassing of an infected area via spanning/bridging (Fig. 24.6). One always however needs to remember that the use of such fixation, especially with combination of other internal fixations and

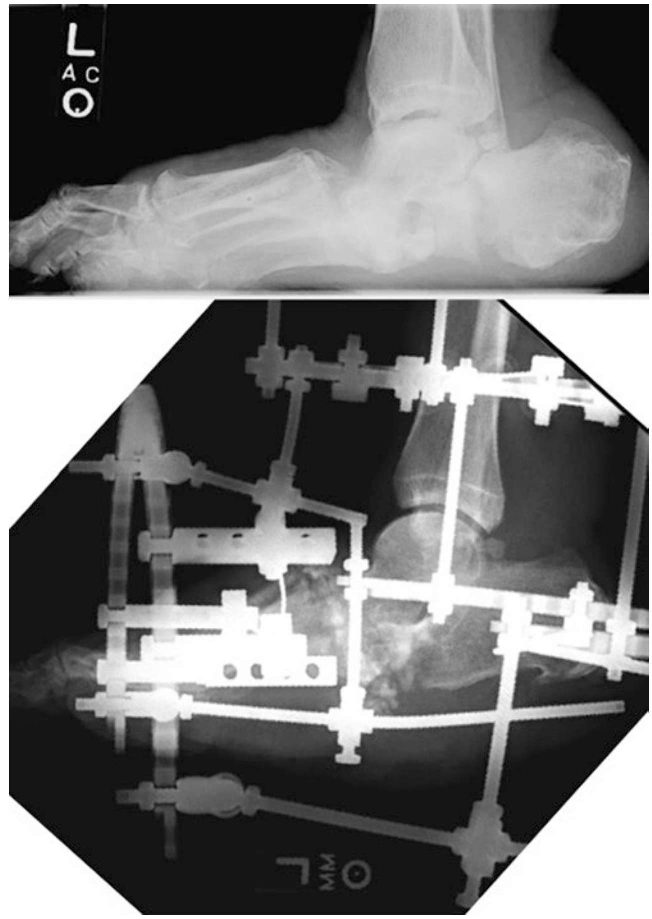


**Fig. 24.6** After resection of infected midfoot bones, antibiotic impregnated bone substitute was packed in the dead space. External fixation was utilized to stabilize the foot while managing the infection and also to gradually reduce the deformity while compressing the forefoot onto the rearfoot to prepare for future arthrodesis with internal fixation

osteobiologics, is very expensive. Cost effectiveness of such construct has not been thoroughly studied. In addition, when it is used as a sole fixation, one has to remember that the external fixation may need to be removed prematurely to avoid pin tract infection prior to bone healing. In combination with internal fixation, it may add extra stability, but a long-term clinical benefit is in question [48]. Pin tract infection is also common [49], yet for a more salvage-type procedure where internal fixation is already attempted or not feasible, external fixation may be the only option (Fig. 24.7).

Gradual correction with dynamic multiplanar external fixation may be another option (Fig. 24.8); however, pin tract infection can be even more prevalent in these immunocompromised patients, especially with the motion and potential loosening of the transfixation wires. Internal fixation can be applied in the second stage with a minimally invasive approach after deformity is corrected [46].

Besides types of fixation, orientation of fixation is also important. The weakest point of fixation will be at the level of Charcot bone or the fusion site. The purpose of fixation is

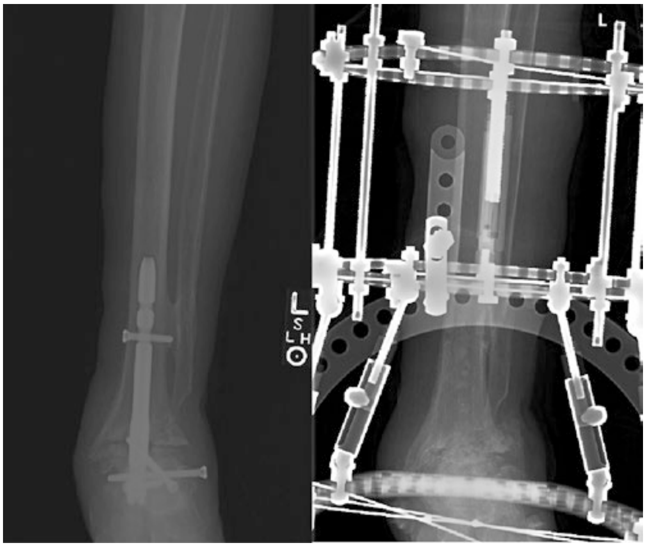



**Fig. 24.7** After an infected retrograde intramedullary nail was removed, a multiplanar external fixation was utilized to maintain stability

normally to stabilize the area until union. However, in Charcot patients, pseudoarthrosis or nonunion is not uncommon. Therefore, fixations need to withstand the weight-bearing force for a long period of time. A long-term structural support may be more important than short-term rigidity in this population.

For midfoot neuroarthropathy, it is important to establish a stable medial column. An unstable medial column can result in a recurrent collapse and/or abduction or adduction of the forefoot. There are several ways to establish long-term stabilization of the medial column. The most common methods are the beaming techniques that are established by an intramedullary screw or a plate-screw construct. An intramedullary screw is inserted in the first ray through the first metatarsal phalangeal joint, through the posterior aspect of the talus or base of the first metatarsal (Fig. 24.9). While a cannulated screw will allow much easier and precise insertion, such a screw is significantly weaker than a solid one. A solid, large core diameter screw is recommended for a stronger construct. If inserted in a retrograding fashion through the first metatarsophalangeal joint, a headless screw is needed. An approximately 3 cm incision can be made plantar to the first metatarsophalangeal joint longitudinally. The joint is then dorsiflexed, and the plantar plate and capsule are incised to expose the head of the first metatarsal bone from the plantar surgical wound. Once exposed, the midfoot is reduced to the plantigrade orientation, and a guide wire is inserted though the first ray before reaming. The reaming can be performed over the guide wire utilizing cannulated instruments that are appropriate for the solid screw size. A good reaming is necessary to insert a large diameter screw without fracturing the first metatarsal.

In order to achieve stability, the beaming screw often needs to reach all the way to the talus even if the talonavicular joint is not affected by neuroarthropathy nor prepared for arthrodesis (Fig. 24.10). The navicular or medial cuneiform is not robust enough to hold the beaming screw in a Charcot patient (Fig. 24.10). As mentioned earlier, when extensive resection of the midfoot is done, the first metatarsal may not align with the long axis of the talus as the first metatarsal may sit medial to the talus in the transverse plane. The first ray may need to be translated laterally or angulated medially to capture the talus.

Alternatively, a plate fixation can be utilized to "beam" the medial column. Often a locking plate-screw construct is utilized for this purpose as it can achieve stronger angular stability at the plate-screw interface. A locking plate-screw construct does not rely on friction created on the plate-bone interface; therefore, preservation of periosteal vascular supply can be managed. With minimally invasive dissection technique, this theoretically aids in bone healing. Yet, clinical benefit of locking plate in Charcot surgery is not extensively studied.

An additional interfragmentary screw may aid more rigidity by achieving absolute stability via compression across the fusion site rather than relying solely on locking plate-screw construct, often used for relative stability. Relative stability, with flexible fixation without compression, in theory can result in secondary bone healing via more biological fixation. However, this needs to rely on natural bone callus formation. In these high-risk neuropathic patients with abnormal biology, this may be difficult. It is unknown at this point which of the healing process, between primary and secondary bone healing, is better in Charcot patients. Yet, it should be reminded that bone healing in neuropathic patients is significantly prolonged, and the fixation devices may fail prior to bone callus formation. On the other hand, excessive rigidity may transfer the stress or strain to other areas and can cause a fracture or acute Charcot process (Fig. 24.11).

Orientation of the plate significantly changes the strength of the beam. A plate applied to the dorsal aspect of the first ray is more subject to bending and fatiguing than one placed on the medial aspect (Fig. 24.12). When the plate is placed in a vertical orientation, like a floor joist, it is much harder to fail with weight-bearing.

Application of the plate more plantarly can result in conversion of the weight-bearing force into compression force via tension banding (Fig. 24.12). However, in order for tension banding to work, the bones must have a strong dorsal cortex. Many Charcot bones are fragile; therefore, a care must be taken to inspect the quality of the bone before attempting this technique.

For transfixation screws, longer screws with multiple cortical purchases are always more stable than unicortical purchases.

For the central rays and the lateral columns, the same principles are applied. While alignment of the lesser rays are

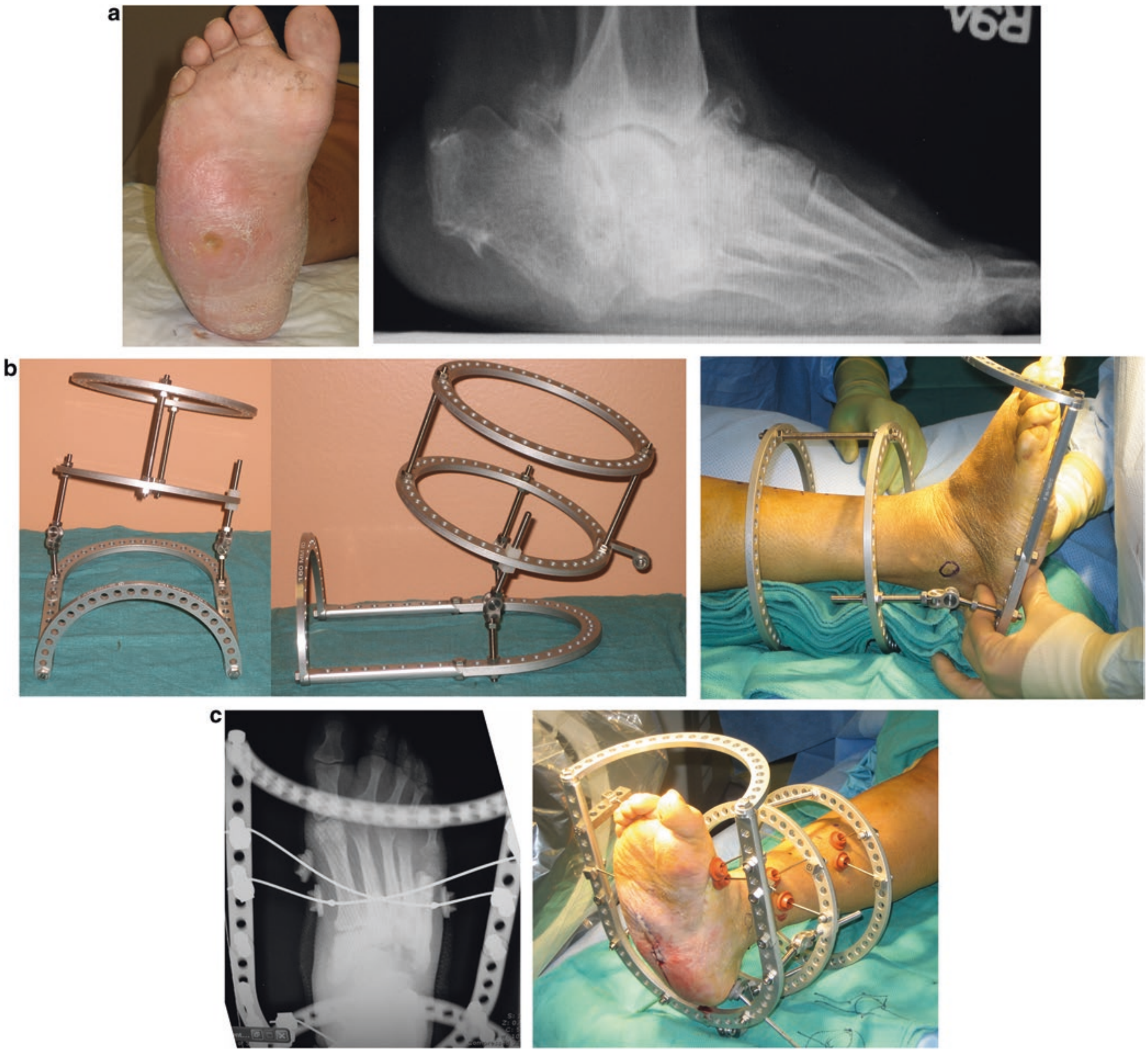


**Fig. 24.8** (**a**) A patient with midfoot osteomyelitis underwent excision of the osteomyelitic bone and gradual correction of the deformity prior to a second-stage internal fixation. (**b**) The patient needed a deformity correction in the frontal and sagittal planes. The hinges of the multiplanar external fixation device were placed over the apices of the deformity. (**c**) The forefoot transfixation wires are also "walked" distally to distract the forefoot

not as critical in the transverse plane once the medial column is established, a patient will not be able to tolerate the malalignment in the frontal or sagittal planes. It can result in forefoot plantar ulceration secondary to increase in focal pressure or a fixation failure if bone healing is delayed.

In the ankle, fixation and deformity correction are little more forgiving. The larger structures with more parallel orientation of the joint to the ground surface afford more stable construct via fixations, such as retrograding intramedullary nail, multiplanar external fixation, and more robust plating systems.

Unlike the midfoot, shortening in the ankle is not beneficial however. Though a permanent brace, such as CROW or AFO, may add some height, a significantly shortened limb may not be any more functional than a proximally amputated extremity with a good prosthesis (Fig. 24.13).

Talectomy with tibiocalcaneal fusion (Boyd's procedure) is often utilized for a severe ankle neuroarthropathy (Fig. 24.14).

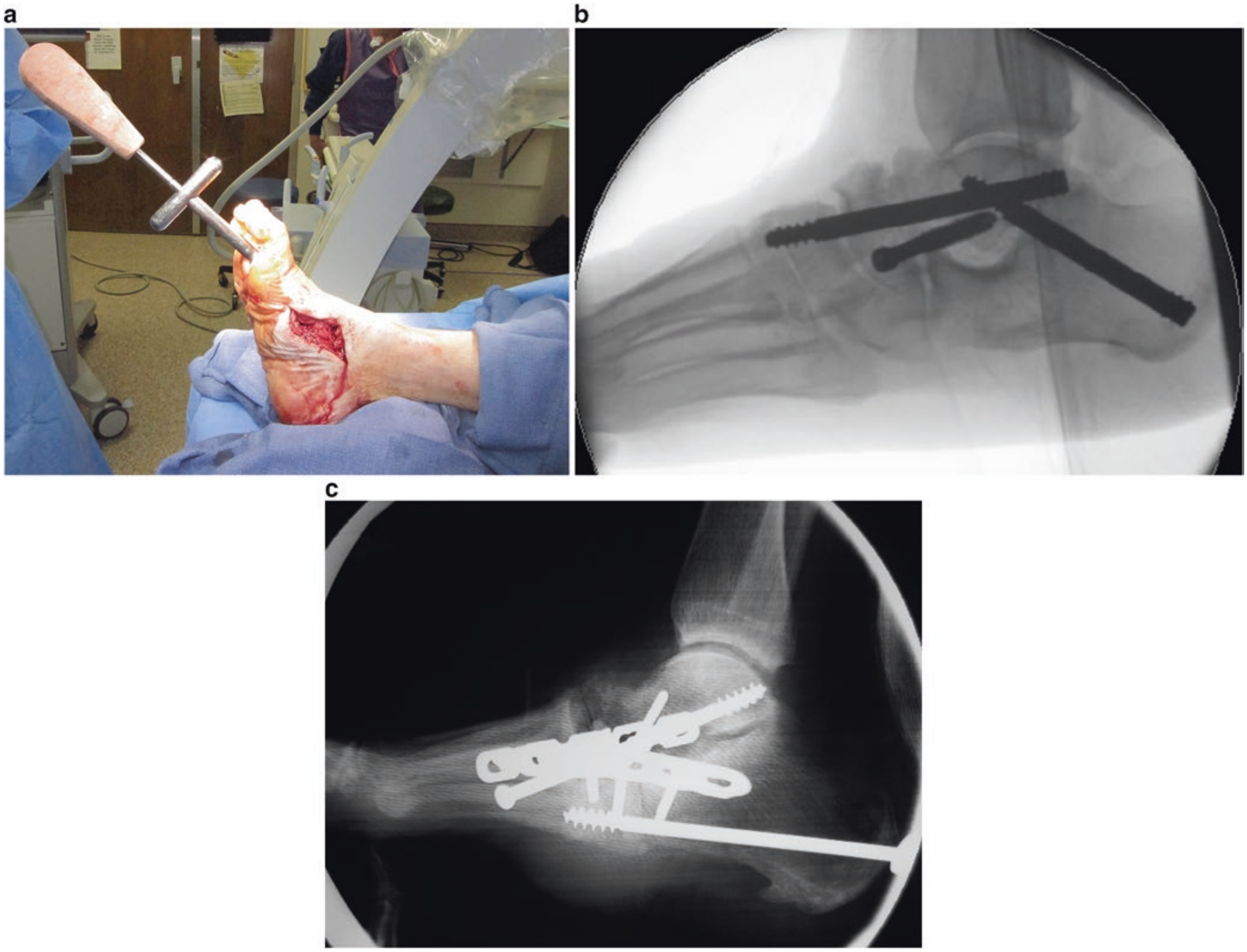


**Fig. 24.9** (**a**) A beaming intramedullary screw is inserted through the plantar incision placed over the first metatarsophalangeal joint. The hallux is dorsiflexed to allow the screw to be in the long axis of the first metatarsal. Alternatively, a screw can be inserted from (**b**) the posterior aspect of the talus or (**c**) plantar aspect of the first metatarsal base

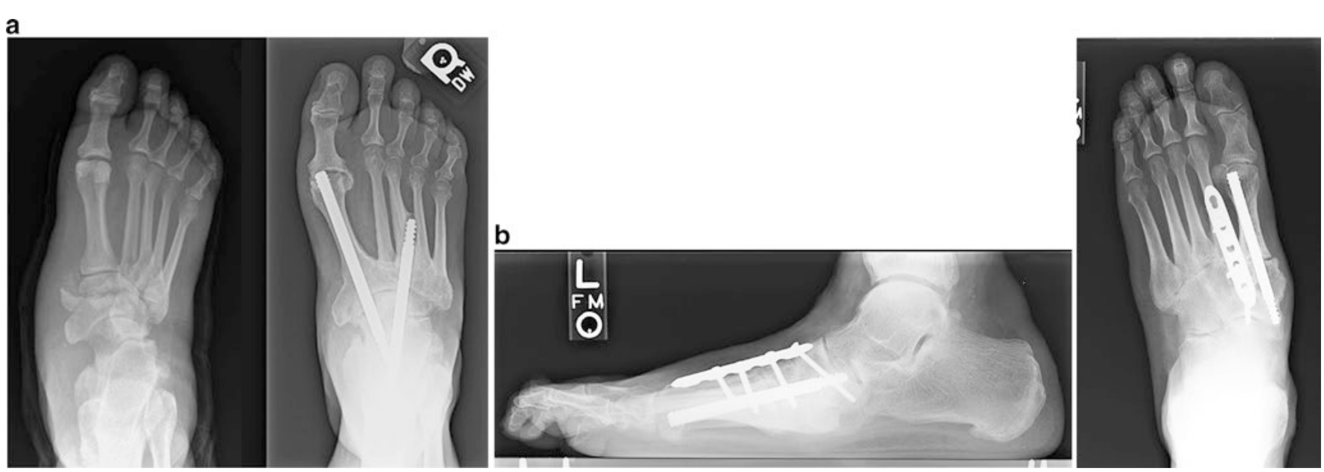


**Fig. 24.10** (**a**) Even though the talonavicular joint was not affected by neuroarthropathy, the beaming intramedullary screw was inserted all the way to the talus for additional stability. (**b**) Without talar purchase, the navicular is not robust enough to maintain the medial column beam

The procedure however results in significant shortening and operative trauma in the extremity. Despite, this can be the only option in many patients short of major amputation. For those with severe, chronic deformity, this may be the

**Fig. 24.11** Though this diabetic patient with severe neuropathy up to the level of the midleg did not develop a Charcot ankle after open reduction and internal fixation, the rigid construct resulted in transfer of the stress and a fracture proximally

**Fig. 24.13** After 6 years from an index talectomy with tibiocalcaneal fusion with external fixation, bony union never took place. Without internal fixation, it resulted in a recurrent dislocation and subsequent below the knee amputation

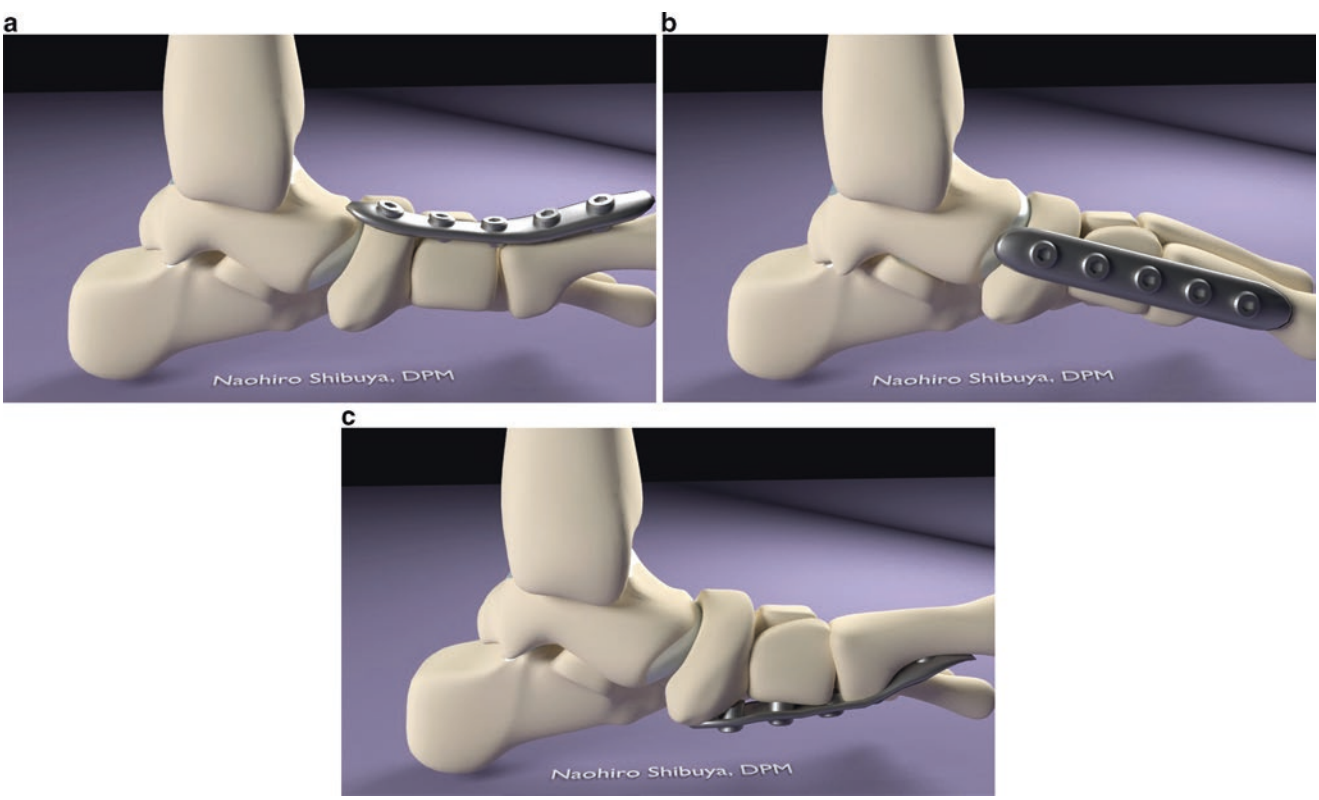



**Fig. 24.12** (**a**) A dorsal plate may fail with weight-bearing force. (**b**) A medial beaming plate is stronger under weight-bearing force due to its vertical orientation. (**c**) A plantar tension banding plate may not work with fragile dorsal cortices

**Fig. 24.14** Acute correction of (**a**) severe, chronic deformity may be possible with (**b**) a simultaneous talectomy and shortening of the limb

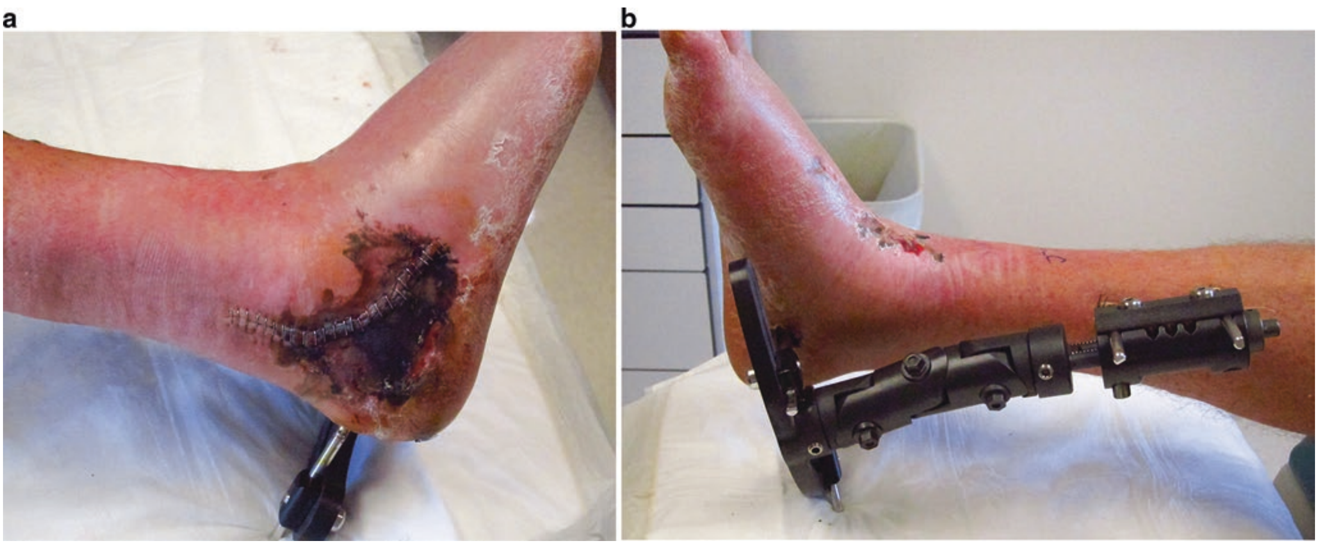


**Fig. 24.15** An acute correction of chronic deformity may result in necrosis due to overstretching of the neurovascular structures

only feasible procedure since acute correction without significant shortening may compromise neurovascular structures (Fig. 24.15).

Addition of bone graft material even with osteobiologic supplementation is not advisable for the same reasons discussed earlier. Surgical trauma itself will "reactivate" the vicious inflammatory cycle (Fig. 24.4), and the bone substitute may be resorbed or "washed out" in the process (Fig. 24.16). An off-label use of bisphosphonates has been suggested to be useful in inhibiting the neuroarthropathic inflammatory process, but the clinical results are inconsistent [50–52].

For fixation in ankle Charcot reconstruction, an intramedullary nail can provide tremendous stability without needing to have significant foreign material underneath the surgical incision. Shah and De demonstrated that the union rate with a retrograde intramedullary nail was higher than that with a unilateral external fixation [53]. However, if infected, a salvage procedure is more difficult.

On the other hand, plate fixation may be better managed in a case of infection because intramedullary tracking of infection may be less likely. However, having the fixations right underneath the incision can be problematic, as postoperative dehiscence of the incision is not uncommon in a Charcot reconstructive surgery. Screw fixation is least stable. Yet, in cases of arthroscopic or minimal incision approach of the ankle arthrodesis, screw fixation can be executed via stab incisions, minimizing operative trauma.

A use of bone stimulator has been studied in Charcot patients [54, 55], yet the effectiveness of bone stimulator in this population is still questionable. Again, having meaningful statistics in a clinical study in this relatively rare disease is challenging.

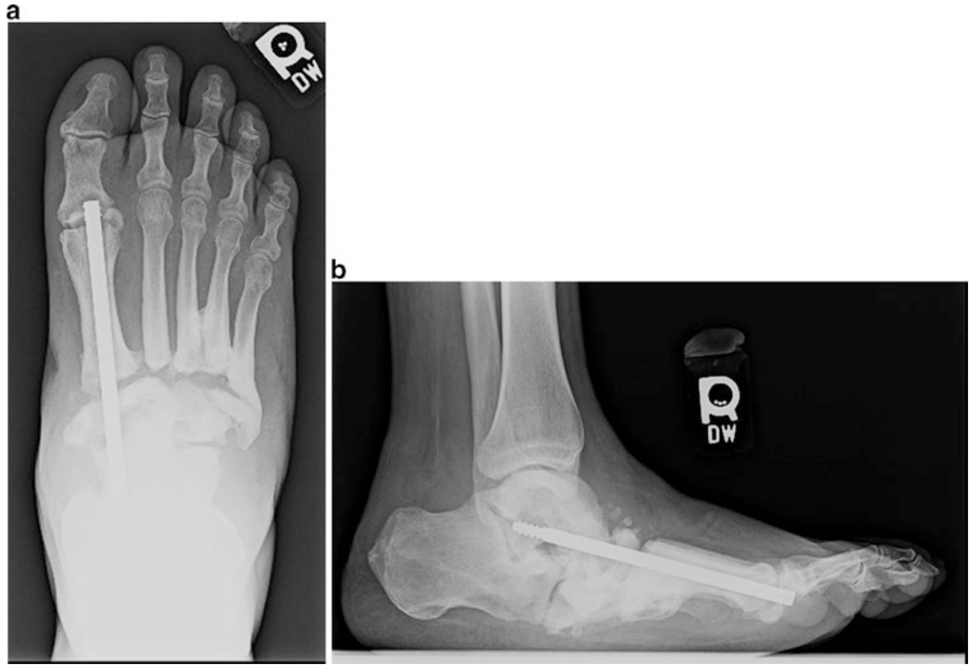


**Fig. 24.16** Bone morphogenetic protein (BMP7) with demineralized bone matrix (DBM) was utilized in attempt to assist the midfoot fusion. However, (**a**) the osteobiologics were completely dissolved along with the postoperative inflammation, and (**b**) the correction was lost

There is no good evidence for use of prophylactic antibiotics in elective foot and ankle surgeries; however, in other areas, especially when hardware is utilized, a routine use of preoperative antibiotics is recommended [56]. There is no evidence for using antibiotics past 24 h after surgery. The Surgical Care Improvement Program (SCIP) guideline recommends against use of antibiotics for more than 24 h after the surgery [57]. Though the guideline was not derived from data in Charcot reconstructive surgeries, a justification to deviate from the guideline may be difficult.

Minimizing hematoma in the surgical site is highly recommended. Charcot reconstructive surgery can traumatic, and many patients often possess major bleeding disorders and/or calcified vessels. Coupled with prolonged surgery and creation of a dead space from extensive resection of necrotic soft tissue and bones, these patients are in high risk for developing hematoma. Hematoma can be minimized by utilizing a drain, releasing the tourniquet prior to closure to identify and eliminate major bleeding, managing medically for a bleeding disorder, adjusting pharmacological agents preoperatively, and applying a compressive dressing and cryotherapy.

Application of compressive dressing and cryotherapy should be done with caution since most of these patients have a significant sensory loss (Fig. 24.17). They are not able to detect abnormal pressure or extreme temperature even after the postoperative block wears off. Education regarding bandaging and cryotherapy and instruction for discontinuation or reporting adverse events are important. Frequent skin inspection and simple vascular examination should also be encouraged. Application of cryotherapy is not indicated at the level of sensory loss [58]. It needs to be proximal enough that the patient is able to feel any discomfort when too cold.

**Fig. 24.17** A tight bandage in a neuropathic patient can result in necrosis of the skin

## Management of Specific Complications

### Hardware Failure

Hardware failure is common in Charcot reconstructive surgeries. When hardware fails, there are a couple of options, including explantation. However, before deciding on a treatment plan, one must investigate the reason for the failure. The reasons can include: infection, inadequate fixation from the previous procedure, high BMI, prolonged bone healing, and unreasonably early weight-bearing.

Charcot reconstruction requires sturdier fixation than most of other reconstructions. When evaluating plain radiographs, one can evaluate the size and orientation of the previous hardware. If the size and orientation of the fixations are adequate in the previous surgery, one can reason that the cause of the failure was due to one or more of other reasons mentioned above. If the size and orientation of the fixations were inadequate, it can be due to the surgical error but still cannot automatically rule out other causes, as more than one cause can be responsible for the failure.

A careful history and physical examination is useful to rule out most of the above-mentioned reasons for the failure. High BMI and excessively early weight-bearing can be ruled out from physical examination and careful history taking, respectively. Infection, however, is more difficult to evaluate (see *infected hardware*) since acute Charcot process can mimic an infectious process.

In most of the cases, prolonged bone healing due to underlying poor biology is responsible for the hardware fatigue and failure. If this is the case, a surgeon has to decide if a revision surgery would be of any benefit when these underlying medical conditions still exist (Fig. 24.18).

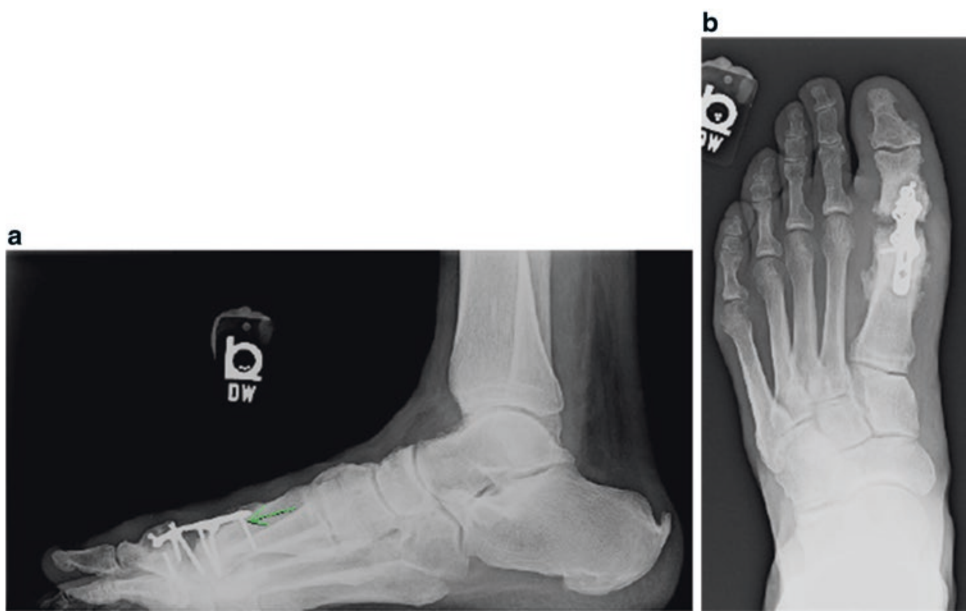
Many failed fixation devices may not be symptomatic. However, when fixation devices are protruding and/or prohibiting wound healing, removal of such implant may be necessary (Fig. 24.19). A prolonged wound closure may lead to colonization and infection. If not infected, an off-label use of a vacuum-assisted wound closure system may be used to grow granulation tissue over the hardware. Hardware removal is necessary to close the wound otherwise.

Some superficial screws can be removed from the open wound in a clinic. When rigid and deep, the patient may need to go to the operating room for removal. Even if stability is compromised, exposed hardware, when resulting in wound complication or infection, may need to be removed. Less foreign material in the open wound can result in better granulation and wound healing. In general, closed soft tissue envelope should be prioritized over stability of the fixation in this high-risk immunocompromised group of patients. A hardware removal may be coupled with application of negative pressure wound therapy to speed up granulation.

Deeper hardware, such as an intramedullary screw or nail, is much more difficult to manage when it fails. Infection and correction of malunion are the few indications for the removal of such deep hardware, as the additional procedure can be very traumatic for the patient (see *malunion, nonunion, infected hardware*).

**Fig. 24.19** The underlying plate and screws are prohibiting wound healing

**Fig. 24.18** When severe neuropathy resulting in osteolysis and hardware failure, revision surgery without modification of underlying medical condition will most likely fail again. This particular patient was non-symptomatic and did not require removal of hardware or revision surgery



## Non-Healing Wound

Unlike a typical neurotrophic ulcer from pressure, wound healing complication in Charcot reconstruction may be subject to a larger problem. Assessing causes of the wound healing complication is necessary before management. Infection, hematoma, lack of biology, and extensive trauma from surgery can all lead to such a complication.

After adjusting for covariates (age, gender, race, BMI, any comorbidity, glycated hemoglobin, and serum glucose), Humphers et al. found that the significant factors associated with postoperative wound healing complication among the diabetics were elevated glycated hemoglobin and the presence of more than one comorbidity. With each % of glycated hemoglobin, the odds of wound healing complication increased by a factor of 1.28. On the other hand, the presence of any comorbidity increased the odds of the complication by a factor of 1.97. Within the comorbidities, neuropathy, high BMI, and smoking history were the ones associated with wound healing complication.

For orthopedic trauma, it has been demonstrated that obesity is a risk factor for wound healing complication [36–41]. Increased tension on the fascial edges at the time of closure with associated increased tissue pressure may reduce microperfusion and oxygen to cause surgical dehiscence [42, 43]. Hematoma and seroma formation are also more common in obese patients and can result in decreased tissue oxygenation and delayed healing [44].

The impact of smoking on wound healing complications has been well studied. Adverse effects of smoking on wound healing include: a temporary reduction in tissue perfusion and oxygenation, impairment of inflammatory cell functions and oxidative bactericidal mechanisms, and attenuation of reparative cell functions including synthesis and deposition of collagen [45]. Smoking cessation therefore is important prior to any revision surgeries. Initiation of smoking cession program 4 weeks prior to elective surgery has been shown to reduce postoperative complications significantly [59]. However, immediate postoperative cessation in orthopedic trauma did not show clinically significantly detectable benefits [60].

While a long-term glycemic control, measured in glycated hemoglobin, have obvious benefit in wound healing, tight management of perioperative serum glucose level may not. While in general perioperative serum glucose control has been believed to be an important factor [1, 2, 7, 13, 17, 23, 25–28], it did not have any statistically significant association with postoperative wound healing complication in foot and ankle procedures [35]. In addition, perioperative serum glucose level can significantly fluctuate. While some literature support tight perioperative glycemic control [29, 30], it remains a controversial topic, as a randomized trial did not demonstrate any added benefit [31].

Nutrient supplementation may be also beneficial in this patient group. Multivitamins, protein, and immune-enhancing supplementation are suggested to be effective [61–70]. Optimizing nutritional requirement is needed prior to considering surgical management.

Besides biology of the patient, biomechanics, ill-fitting brace/shoe, and infection (see *osteomyelitis*) can be responsible for non-healing open wounds. If available, pedobarograph is useful in assessing the degree and location of the planter pressure (Fig. 24.20). Without significant focal pressure present in the pedobarograph, one can deduce that the cause of the open wound can be due to lack of biology, compliance, or underlying infection.

Conservatively, these open wounds can be treated with any advanced wound care modalities; however, in many situations, aggressive off-loading may be necessary in this population. Off-loading can be achieved by reducing both focal pressure and activity level. Therefore, a cumbersome total contact cast, rather than off-loading boots or shoes, is more effective in healing wounds, as it also reduces the activity level significantly [71].

Though many of the focal pressures can be accommodated with a brace or shoes, some do not respond to orthotic management. Exostectomy or planing should be attempted if indicated prior to considering reconstructive surgery. With a general rule, a rigid Charcot foot is more manageable with exostectomy or planing (Fig. 24.21), while more flexible Charcot foot can result in further collapse. Ligamentous structures, which stabilize osseous structures, are often disrupted even with a simple exostectomy (Fig. 24.22). Simultaneous internal or external fixation without arthrodesis may be considered, but the long-term benefit of this is unclear (Fig. 24.23).

It should be reminded that the simple exostectomy could also initiate the viscous inflammatory process and potentially result in a recurrent acute Charcot process. This may propagate the rocker bottom foot and may worsen the biomechanics. Prolonged immobilization, tight glucose control, and possibly the off-label use of bisphosphonates may be helpful to prevent the occurrence of a neuropathic inflammatory process. Off-loading external fixation has been suggested by a few, but the cost utility is unclear in this situation.

Transfer lesions to the forefoot (from plantarflexed forefoot in malunion or under-corrected equinus) or subcalcaneal area (from over correction of equinus) can also be common. Percutaneous osteotomy with or without fixation can raise the corresponding metatarsal bone to off-load the metatarsal head in those with submetatarsal ulceration. A flexor hallucis longus tendon transfer may reduce enough pressure to heal the subcalcaneal lesion (Fig. 24.20).

Primary closure, skin grafting, and local flaps are other options for treatment of the open wound [72–74]. Evaluation

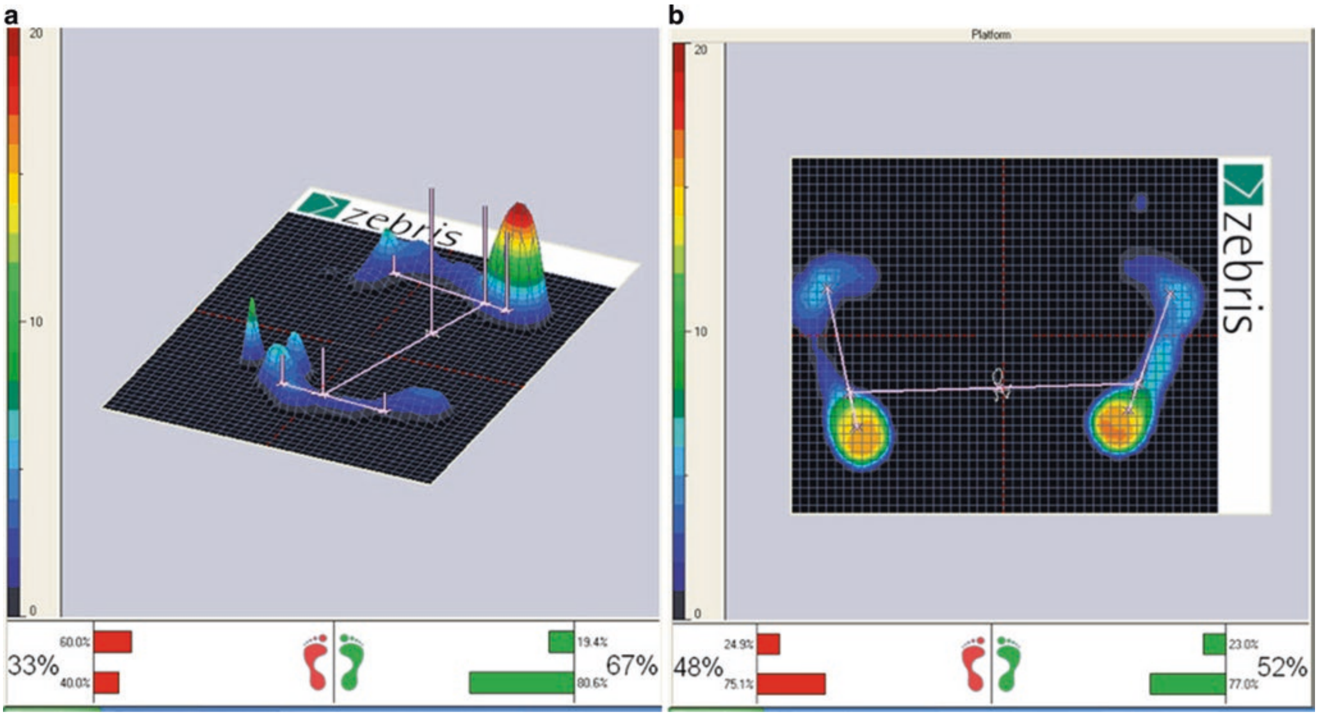



**Fig. 24.20** (**a**) The pedobarograph shows an obvious increase in plantar calcaneal pressure in this patient with a plantar heel ulcer secondary to overlengthening of the Achilles tendon. (**b**) After flexor hallucis longus tendon transfer, the plantar pressure is reduced and the ulcer is healed


**Fig. 24.21** (**a**) The patient developed a chronic plantar wound secondary to the rocker bottom foot type. (**b**) This chronic rigid Charcot foot was treated with plantar exostectomy. (**c**) Though normal foot architecture is not restored, the patient has not needed reconstructive surgery

**Fig. 24.22** To reach the bony prominence, plantar soft tissues including ligamentous structures are violated

of healing potential in these high-risk patients is again paramount, especially when more aggressive and traumatic soft tissue reconstruction is considered.

## Malunion

Definition of malunion may be significantly different in a Charcot population than other foot and ankle conditions. In many Charcot cases, restoration of anatomical architecture of the foot and ankle may not be necessary, practical, or even beneficial. A “plantigrade” foot is the term often used to describe the final, acceptable result in diabetic Charcot reconstruction. This often means a reasonably functional and “brace-able” foot that can withstand the activities of daily living. The functional foot does not necessarily always provide a propulsive gait.

One of the most important aspects of Charcot reconstruction is to achieve the plantigrade foot without focal pressure

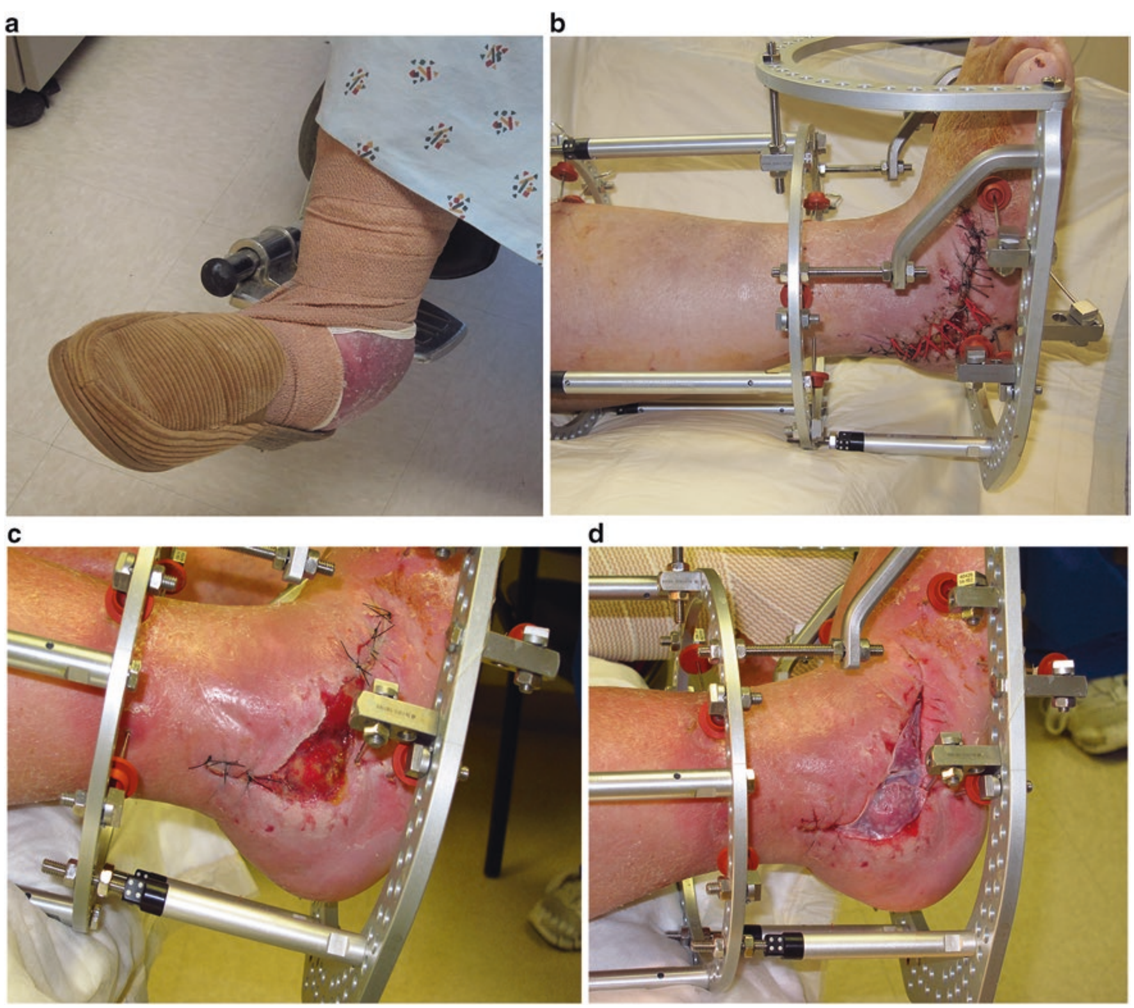



**Fig. 24.23** An acute Charcot dislocation with chronic lateral ankle wound was stabilized without arthrodesis, followed by advanced wound care modalities

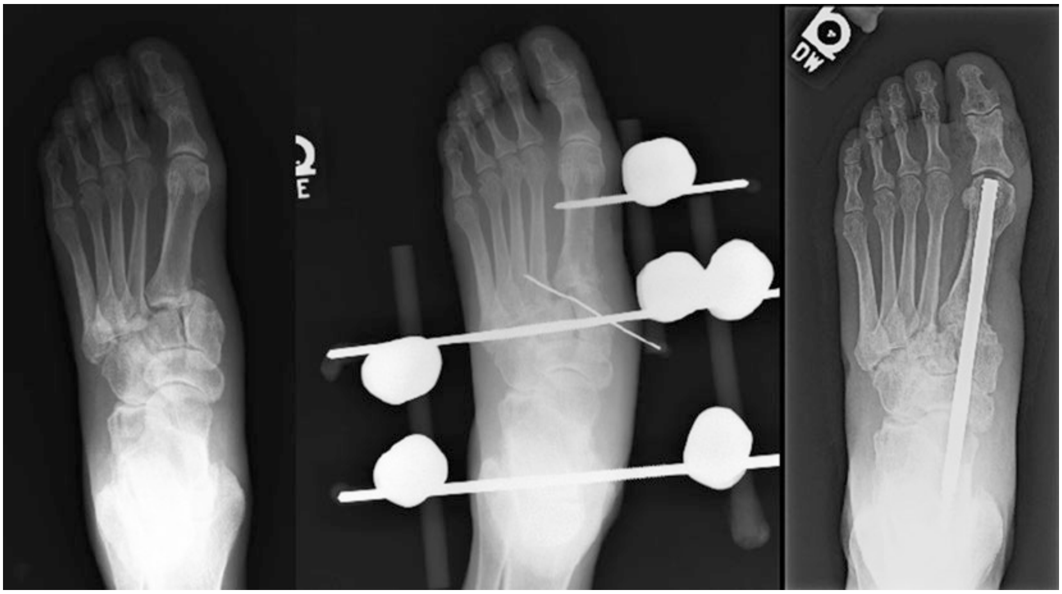


**Fig. 24.24** While the close reduction with external fixation did not reduce the deformity fully, a subsequent minimally invasive open reduction and internal fixation with 3 cm incision over the tarsometatarsal joint, performed after the acute Charcot phase, provided an adequate reduction of the deformity and permanent fixation. Though naviculocuneiform and talonavicular joints were not prepared for arthrodesis, the beaming screw was inserted all the way down to the talus for additional stability

points that predispose to future neuropathic ulcerations. Severe malunion may lead to biomechanical problems that result in increased plantar, medial, lateral, and even dorsal pressure in a brace. When underlying arthrodesis is solidly fused, one may want to consider exostectomy, partial resection, or amputation before reconstruction to minimize operative trauma. It is difficult for a patient to go through multiple rehabilitation processes in a short period of time from multiple reconstructive surgeries. Inactivity and deconditioning in these patients significantly affect their mortality and quality of life. A long, thorough discussion with a patient and his/her family is critical before deciding to revise the malunion.

Pain is usually not a symptom from malunion in a neuropathic patient. When painful, there may be an underlying nonunion. In a subtle case, evaluation with a CT scan can aid identifying nonunions.

Malunion can be resulted from a previous poor surgery, infection, progressive deformity before union, and/or newly onset of acute Charcot arthropathy. If the reason is due to progression of deformity before union, then the cause of the delay union should be investigated (see *nonunion*). If a recurrent acute neuroarthropathy is not resulting in severe deformity, then the patient should be treated conservatively with protected weight-bearing with a total contact cast or complete off-loading with a wheelchair if practical. If the main cause of the nonunion was due to poor previous surgery and the patient is relatively healthy and undisturbed (still possessing adequate vascular supply, non-compromised skin and bone stock), revision reconstructive surgery may be indicated.

Some of those general pearls used for primary Charcot reconstruction can be applied for a revision surgery. However, one needs to remember that neurovascular structure is further compromised, and these patients may be significantly deconditioned from the previous surgery.

Understanding location of previous incisions is extremely important. It can help predict the status of the remaining functional neurovascular structures. These surviving neurovascular structures should be preserved at all cost. Less invasive technique is often needed to preserve those neurovascular supplies (Fig. 24.24).

To start planning for a revisional reconstructive surgery, the rearfoot alignment to the leg should be evaluated first. The calcaneus should be directly under the mechanical axis of the lower extremity or slightly lateral to it, as a varus ankle and foot is extremely difficult to brace. In some instances, a simple calcaneal slide osteotomy is enough to shift the center of pressure to relieve the symptoms, such as ulceration or progression of the deformity. Similarly, presence of equinus should also be inspected. Often, these patients have some type of posterior muscle group lengthening procedures in the past. Overlengthening of the previously lengthened posterior soft tissue structures should be avoided, as a excessively dorsiflexed calcaneus is significantly more difficult to manage than equinus.

Once the ankle level is thoroughly evaluated, one can look at the foot deformity. Many malunions result in a collapse in the sagittal plane with severe abduction or adduction of the forefoot to the rearfoot. The same principle as flatfoot reconstruction may be applied to regain the "tripod" in

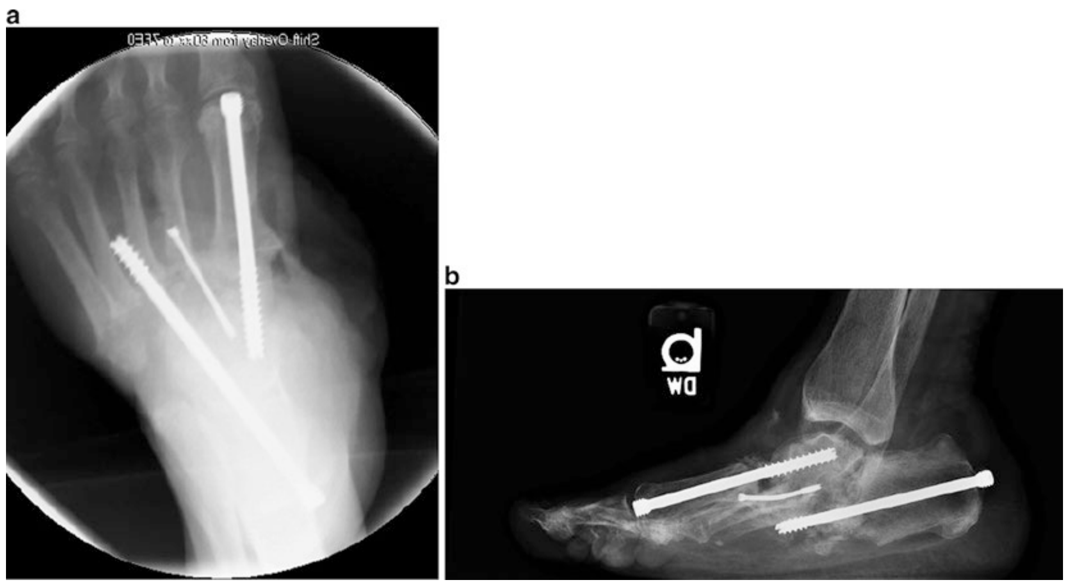


**Fig. 24.25** (**a**) The medial column was shortened significantly more than the lateral column, and this resulted in an inadequate "tripod" of the foot. (**b**) The future consequences include a collapse of the medial arch from compensation of the iatrogenic forefoot varus deformity

the foot. Though it is not necessary to create a high "tripod," the concept is still important to avoid a future collapse. When the forefoot is in a varus position, the rearfoot or ankle can go into valgus to compensate for the forefoot deformity, especially when the midfoot is rigid from the previous arthrodesis. Similarly, an excessively short medial or lateral column can result in an inadequate "tripod" and can result in a future collapse (Fig. 24.25)

For correction of the foot deformity, further resection rather than bone block distraction osteotomy is suggested for the same reasons discussed earlier. Fixation can be more difficult in the revision surgery as less bone stock is available. Combination of internal and external fixation may be necessary to achieve a solid reconstruct without disturbance of both the endosteal and periosteal vasculature.

## Nonunion

The main reason for nonunion in Charcot patient is stemming from the underlying medical conditions. Therefore, revision surgery in those patients may not be indicated. If the previous reconstruction was done by an experienced surgeon, yet resulted in nonunion, the chances of the second surgery resulting in union are minimal unless there are modifiable medical/social factors that can be adressed.

Diabetic bone healing complication in particular has been extensively studied in animal models [75–99]. In humans, incidence of bone healing complication in diabetic patients is believed to be high in foot and ankle surgeries as well [100–107]. Within a diabetic population, the association of hyperglycemia with bone healing complication has been well documented [76, 82, 83, 90, 91, 93, 97, 100, 108, 109], yet little clinical information is available regarding other diabetes-related comorbidities or conditions directly affecting bone healing. In diabetic animal models, there have been many theories suggesting the causes of bone metabolism disturbance, yet translational research is lacking to link the significance of those theories in a clinical practice.

In a case-control study of diabetic patients, approximately one out of four patients had one or more bone healing complications [110]. The study showed that a patient with glycated hemoglobin level of more than 7% had roughly three times greater odds of getting a bone healing complication. However, the most significant factor associated with bone healing complication in this diabetic cohort was presence of neuropathy. The diabetic patients with neuropathy had four times the odds of having bone healing complication than diabetics without neuropathy. This result coincides with many animal studies as well as clinical reports that indicate that bone healing complication can be due to malfunctions of bone metabolism resulting from neuropathy [104, 111–114]. Lack of adequate neuropeptide release in these patients may upregulate osteoclastogenesis while downregulating osteoblastic activities [111, 115–117]. Unfortunately, all Charcot patients fit into this category.

The same study also showed that every 10 min of operative time was associated with diabetic bone healing complications by the factor of 1.15. While a longer surgery may confound more complex cases or an inexperienced surgeon, this finding makes us rethink the need for an extensive surgery in this high-risk population.

If the nonunion was mainly due to poor surgical technique or noncompliance, then a revision surgery may still be beneficial. Yet, pseudoarthrosis with a "brace-able" foot does not have to be surgically managed. Conservative approach should be exhausted before attempting a surgical reconstruction.

Generous resection of nonviable bone is paramount to a successful fusion. Also, sturdy fixation without requiring significant operative trauma is important (Fig. 24.26).


**Fig. 24.26** This patient with nonunion and recurrent deformity was considered to have inadequate fixation. Sturdier fixation was utilized to achieve union in the revision surgery

The same principles for surgical reconstruction described in the previous section still apply to this revision surgery. More prolonged non-weight-bearing status may be necessary to achieve union in the revision surgery. However, the surgeon has to account for potential deconditioning and decline in quality of life when deciding to go through another prolonged rehabilitation process. A patellar tendon bearing ankle-foot orthoses or Charcot restraint orthotic walker may be needed to get the patient back in activities earlier without significant weight-bearing force applied to the surgical site (Fig. 24.27).

## Infected Hardware/Soft Tissue Infection

When a patient with previous Charcot surgery presents with a red, hot, swollen foot/ankle, the differentials should include infection, recurrent neuroarthropathy, and DVT. It is important to remember that the infection may not present in a typical fashion. Often, the patient may not have any systemic symptoms or leukocytosis.

In trauma, when hardware is infected, the general rule is to leave the implant until union. However, because many Charcot reconstructive surgeries result in delay/nonunion or pseudoarthrosis, waiting for union may not be desirable. In addition, the patient is often immunocompromised; therefore, the same principle should not be applied to Charcot patients. Immediate and aggressive pharmacological and surgical treatment of the postoperative infection is warranted (Fig. 24.28).

**Fig. 24.27** (**a**) Charcot restraint orthotic walker and (**b**) patellar tendon bearing brace shortens the duration of inactivity. Especially when a patient is undergoing revision procedures, deconditioning of the patient needs to be minimized


**Fig. 24.28** (**a**) Deep pin tract infection extending to the dorsal and plantar foot was immediately treated with (**b**) removal of external fixation, incision and drainage, and aggressive wound care. (**c**) The infection was eradicated

Once hardware is removed, reaming or curettage of the area may be necessary to debride the adjacent bone to remove infection. In a case of intramedullary screw or nail, the reamer that is slightly larger than the one used in the previous surgery can remove the thin layer cancellous bone that may be infected. The dead space now should be replaced with antibiotic impregnated cement or bone substitute (Fig. 24.29). The cement rod or spacer can be replaced with bone graft in 2–4 weeks. It is also important to evaluate the extent of infection in the bone, as it may be necessary to debride more than the thin layer adjacent to the fixation device (see *osteomyelitis*).

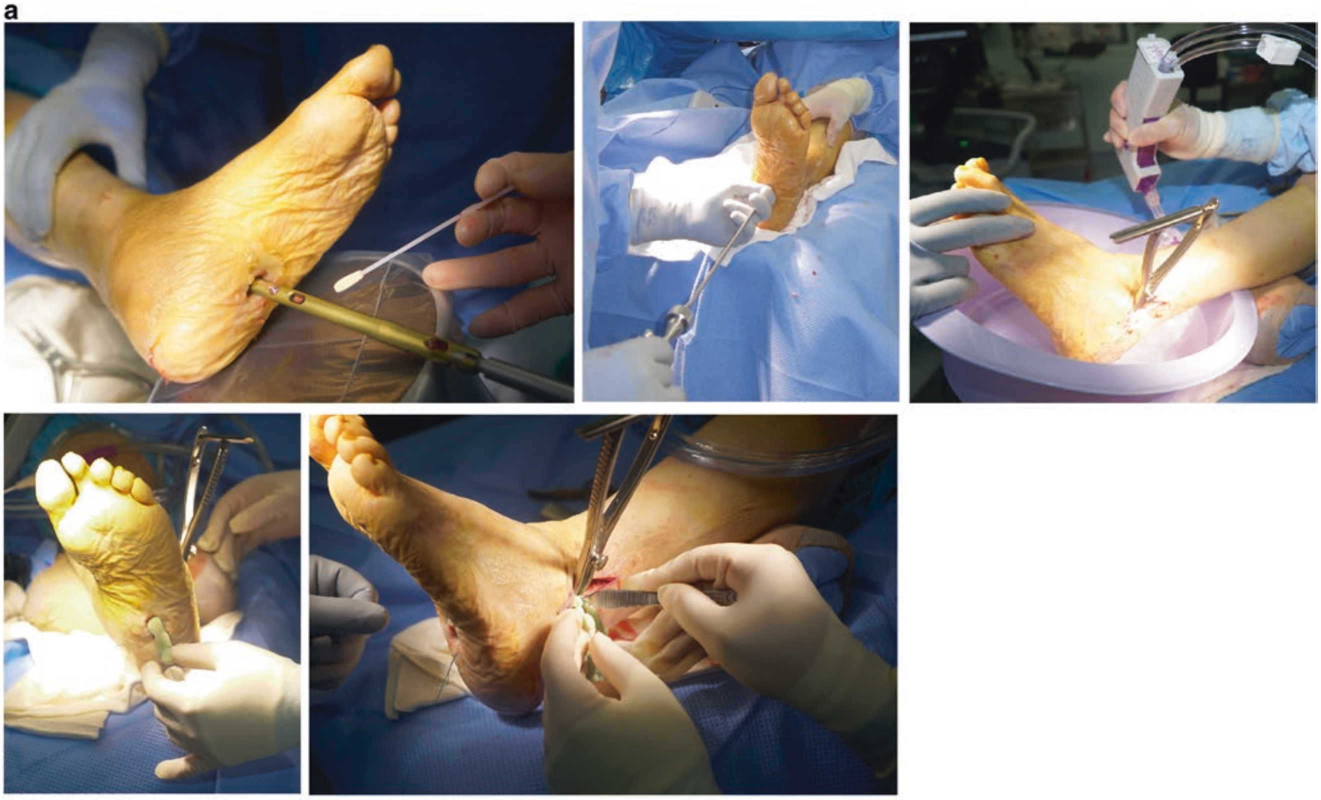
Within a diabetic population, it has been demonstrated that elevation in glycated hemoglobin and having more than one comorbidities were statistically significantly associated with postoperative infection in diabetics [35]. However, adjusting for all the relevant covariates (age, gender, race, BMI, presence of any comorbidity, glycated hemoglobin, serum glucose, and type of procedure (osseous vs. soft tissue)), only glycated hemoglobin was significantly associated. Each 1% in glycated hemoglobin increased the odds of infection by a factor of 1.59. Therefore, tight long-term control of glucose in diabetic patient is once again the important factor. With a *post hoc* analysis, neuropathy was the only factor among the comorbidities that was associated with the postoperative infection in diabetics. This is in agreement with other authors, who show that peripheral neuropathy is the risk factor for postoperative infection [13, 32–35].

Treatment of soft tissue infection can be initiated with antibiotics and surgical debridement. Aggressive debridement is needed for eradication of the infection without multiple trips to the operating room. A staged, delayed primary closure after subsidence of inflammation and infection, as opposed to a one-stage procedure, minimizes further wound dehiscence or separation. Appropriate consultations, such as infectious disease, are also recommended. A multidisciplinary approach to treat complications in these high-risk patients cannot be overemphasized.

## Osteomyelitis

Differentiating an acute, surgically induced neuroarthropathy process from bone infection is often difficult; therefore, keen diagnostic skills are needed to treat these complications correctly in a timely manner. Often both radiographic and laboratory workups are necessary. Though bone biopsy is considered the gold standard, a negative result may not necessarily rule out osteomyelitis. Multiple biopsies taken from different sites may be needed to capture osteomyelitic specimen if present.

American College of Radiology Appropriateness Criteria suggests that only plain X-rays or MRI have an evidence-based indication for detecting osteomyelitis in diabetic patients with neuropathic arthropathy [118]. An MRI can show tracking of osteomyelitis along the medullary canal in a



b

**Fig. 24.29** (**a**) The infected intramedullary nail was removed and cultured, and the medullary canal was reamed. The medullary canal was then irrigated and filled with antibiotic impregnated cement nail and beads. (**b**) After infection subsided, the antibiotic impregnated cement was replaced with autograft, and external fixation was applied for stabilization and dynamic compression, by passing the area of infection

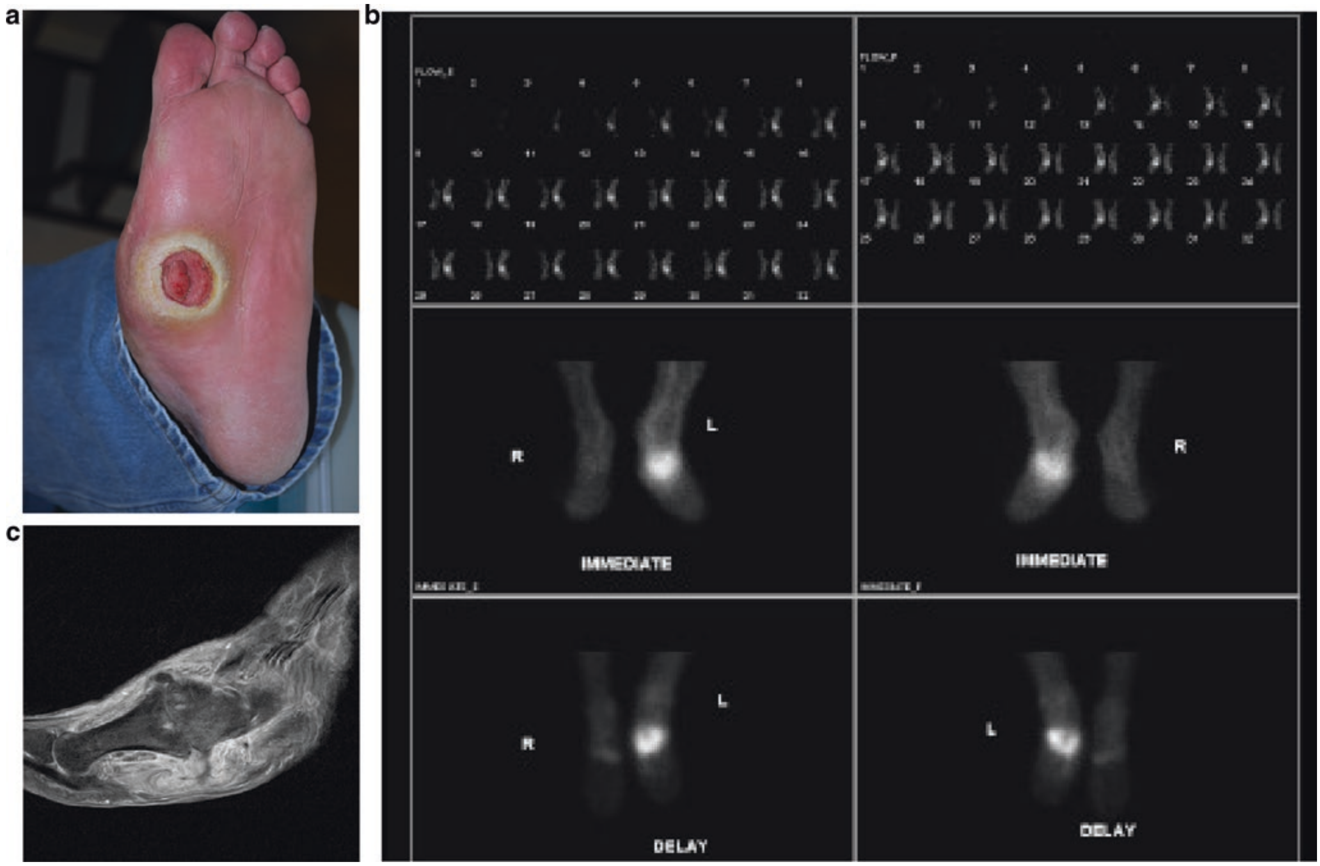



**Fig. 24.30** (**a**) While the open wound probes deep and (**b**) a technetium scan shows significant uptake in the midfoot, (**c**) the MRI shows diffuse marrow edema adjacent to the tarsometatarsal joint with subchondral cysts and without medullary tracking, suggestive of an acute Charcot process rather than osteomyelitis

a long bone. In Charcot arthropathy, diffused marrow edema is found in periarticular areas of multiple bones (Fig. 24.30). Contrast may be used to show clear extent of the infected or necrotic bone and for surgical planning. Other studies such as nuclear scans (including technetium-99, labeled leukocyte scan, indium-111, and sulfur colloid), ultrasound, CT scan, and PET/CT do not have good ratings to be used for this situation according to the guideline.

Inflammatory markers may also be useful in diagnosing osteomyelitis. Use of sedimentation rate, C-reactive protein, and procalcitonin have been studied and considered useful [119, 120]. Serial laboratory examination of these markers is also useful after surgical debridement for a monitoring purpose.

The “probe-to-bone” test is popular, yet its effectiveness is greatly dependent on a situation [121–125]. Positive and negative predictive values of this test are affected by a population in which the test is utilized. This is also true for abovementioned laboratory tests for inflammatory markers. In a higher-risk patient population, positive predictive value suffers, as prevalence of a deep wound is higher. Especially in the postoperative patient population, probing through the dehisced surgical wound does not necessarily mean osteomyelitis.

Once determined osteomyelitis, resection of the infected bone, unless proximal amputation is indicated, should be planned. Long-term antibiotic treatment of osteomyelitis has also been shown effective [126]. However, it is unclear to which type of patients can be treated effectively with the nonsurgical approach, as a thorough risk factor assessment has not yet to be conducted in a clinical research. Patients with minor non-symptomatic osteomyelitis or high anesthesia risk, who are no longer a surgical candidate, may be benefitted from a long-term or lifetime antibiotic suppression therapy. Again, consulting an infectious disease specialist is recommended.

Typically, aggressive excisional debridement of osteomyelitic bone is needed. Again, an MRI with contrast may be effective in showing the extent of the necrotic bone. Once extent of the excision is determined preoperatively, the surgeon has to determine if the resultant foot will be stable. If not, one should reconsider amputation and its advantages over local debridement and staged reconstruction (Fig. 24.31).

For staged procedures, the priority of the initial surgery is to resect the osteomyelitic bone. Enough bone needs to be resected to limit the number of operations. One may supplement it with antibiotic impregnated beads or spacer to eradicate the infection. Postoperatively a surgeon can follow

**Fig. 24.31** (**a**) The patient developed osteomyelitis in the remaining talus. The talus was resected along with the infected soft tissue and (**b**) stabilized. Though the infection was eradicated, (**c**) the resultant foot was not functional. The patient ended up with a below the knee amputation

these patients with serial serum inflammatory markers to monitor the progress, and once the markers are normalized and soft tissue inflammation is resolved, a delayed arthrodesis may be attempted.

Alternatively, some may use antibiotic impregnated bone graft substitutes to attempt arthrodesis in a one-stage procedure. However, a care must be taken, as the bone substitutes can act as a foreign material once the efficacy of the antibiotics wears off, and it may result in further inflammatory processes. Also, soft tissue is often compromised from the infection, and wound healing can be difficult in a one-stage approach.

## Minor Amputation

We often assume that a patient is more satisfied with a limb salvage attempt, yet this may not be true in many situations. The patient may have a better quality of life with minor amputation than having to deal with a chronic wound [127]. The burden of dressing changes; long-term non-weight-bearing status and office visits can all account for lower quality of life. In Charcot patients, the deformity decreases the patients' function, but it has been documented that mental status of the patients may not be any different when compared to patients with neurotrophic ulceration without Charcot arthropathy [128, 129]. Again, this would question the need for reconstruction in many of these patients. Considering their high mortality rate and low 5-year survival rate [31], amputation over salvage should be a part of discussion in treating these patients.

Besides eliminating infection, the purpose of amputation can also be to reduce the biomechanical stress. We often think of amputation as a last resort, non-salvage procedure, which does not require good surgical skills; however, a successful amputation that can withstand a long-term biomechanical stress can be as challenging as reconstructive procedures. Especially at the foot and ankle levels, a surgeon must have a good understanding of biomechanics to limit recurrent/transfer lesions or further amputation.

Location and level of minor amputation depends on the reason for the amputation and the current neurovascular status. Transmetatarsal amputation over ray resections has been more accepted for long-term biomechanical stability. Transmetatarsal amputation is also superior to Chopart's amputation because many of the tendon insertions are spared in transmetatarsal amputation: Both peroneals and tibialis anterior can still function after tramsmetatarsal amputation.

Both Chopart's and Syme's amputations are more difficult to brace. An experienced prosthetist is required to minimize recurrent ulceration and to maximize function.

## Proximal Amputation

Salvage versus amputation has been evaluated extensively for years. In trauma patients, the studies fail to support salvage over amputation in terms of length of stay in the hospital, pain level, quality of life, function, and time to go back to work [130, 131]. In trauma, it has been found that male gender, occurrence of confounding injury, presence of a fracture, and an open wound are associated with occurrence of lower extremity amputation [132]. Similarly, in a high-risk diabetic population, male gender, having more comorbidities, history of open wounds are more susceptible to amputation [30]. Patients with neuroarthropathy possess many of these characteristics.

Major amputations, such as below the knee amputation, may be indicated when the patient's medical condition inhibits healing despite limb salvage efforts. Further, it is also dependent on a patient's preference based on his/her lifestyle, quality of life, and natural disinclination to lose a body part. It is important to remember in a revision surgery, especially in those with neurovascular diseases, that the previous surgery has insulted already-compromised neurovascular structures. Many of the complications are stemming from the patient's underlying medical/metabolic condition, compliance, and incapacity to rehabilitate. Therefore, a well-executed surgical revision may still not be sufficient to ameliorate the situation.

Depending on severity of the complication, proximal amputation above the level of area that is not affected by severe peripheral neuropathy may be the best option for the patient, who has been battling with this condition for a long time. As discussed earlier, neuropathy is the single most important risk factor that is associated with bone and soft tissue complications. Therefore, going above the level of neuropathy is often necessary to avoid further complications.

A popular belief in our community is that lower extremity amputation is a proximal cause of death [133], and many consider that limb salvage efforts are critical. However, the evidence on this phenomenon is not conclusive [134–136]. Although it is known that amputation does have an impact on vascular dynamics [137–139], it is difficult to find direct evidence that amputation leads directly to death. Underlying disease may play a larger role in eventual mortality than the amputation itself.

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