Superconstructs in the Treatment of Charcot Foot Deformity: Plantar Plating, Locked Plating, and Axial Screw Fixation

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KEYWORDS

• Charcot • Neuroarthropathy • Superconstruct • Diabetic Foot
• Limb Salvage • Arthrodesis • Axial Screw • Plantar Plate

Painless fracture dislocation associated with neuropathy in syphilitic patients was described by Jean Mation Charcot.[1] In 1936, Jordan[2] linked neuropathic fractures to diabetes. With the increasing prevalence of diabetes and neuropathy, the treatment of Charcot neuroarthropathy has become an increasingly important part of the clinician's practice. Nonoperative treatment has included total-contact cast immobilization until bony consolidation occurs, followed by accommodative bracing and footwear.[3–5] Surgery has often been reserved for patients who develop gross deformity with ulceration, and limited to simple resection of bony prominences.[6–10] Unsatisfactory outcomes in patients who have grossly unstable dislocations in the midfoot and increased instability following bony resection have led to changes of treatment protocols for neuropathic deformity.[11–24] The diabetic patient commonly has comorbid conditions involving the lower extremities, including peripheral neuropathy, peripheral vascular disease, and immune impairment. These conditions worsen with time, making late reconstruction challenging. These issues combined with progressive bony deformity and resorption that may accompany neuroarthropathy have led to advocating surgical intervention earlier in the disease process.[23]

The long-term goals for operative and nonoperative treatment are to achieve a stable, plantigrade functional foot that is resistant to ulceration, to prevent amputation, to improve performance in activities of daily living, and to allow the use of nonprescription footwear. Chronic dislocation and soft tissue contracture often require significant bony resection at surgery to restore alignment. Midfoot arthrodesis with

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bony resection and osteotomy is a technique considered appropriate for early treatment of this deformity; however, loss of initial surgical correction and high rates of nonunion still remain common sequelae.[3,9,15,17,20] Poor bone quality, neuropathy, poor vascularity, and impaired nutrition of glycosylated tissue in diabetic patients all delay healing of the arthrodesis. Standard fixation techniques are often inadequate to maintain alignment postoperatively. In addition, patients who have neuropathy frequently have difficulty complying with long periods of non–weight bearing needed to achieve arthrodesis.[19,22,25] Previously described techniques include fixation with dorsal or plantar plates, crossed lag screws, fixation with axial screws from the talus and calcaneus, and external fixation.[12,14,21,22,26]

CLASSIFICATION

Multiple classification systems have been proposed to describe the deformities associated with neuroarthropathy of the foot and ankle. Brodsky and Rouse[6] classified neuroarthropathy based on location: disease in the midfoot (type 1), the hindfoot (type 2), the ankle (type 3a), and avulsion fracture of the calcaneus by the Achilles tendon (type 3b). Disease in multiple locations was classified as type 4, and disease in the forefoot was classified as type 5.

In 1998, Sammarco and Conti,[20] and Schon and colleagues[27] described similar radiographic classification systems of Charcot midfoot deformity associated with neuroarthropathy. The Sammarco classification was presented with a series of 27patients who had midfoot neuroarthropathy and were treated with surgical reduction and arthrodesis[20] (**Fig. 1**). Five patterns were identified: pattern 1—diastasis of the first and second metatarsals with fragmentation and collapse extending across the tarsometatarsal joint; pattern 2—medial metatarsal-cuneiform destruction without diastasis of the first and second metatarsals; pattern 3—arthropathy at the navicular-medial cuneiform joint with fragmentation of the middle cuneiform and destruction across the lateral tarsometatarsal joints; pattern 4—arthropathy of the first metatarsal-medial cuneiform joint with diastasis between the first and second metatarsals and proximal and lateral extension into the intercuneiform joints ending at the calcaneocuboid joint; and pattern 5—perinavicular arthropathy with distal intertarsal extension.

Later that year, Schon and colleagues[27] published radiographic and clinical classification systems for midfoot neuropathic deformity (**Fig. 2**). The radiographic classification was developed after reviewing the weight-bearing radiographs of 131 neuroarthropathic feet. This classification is based on the anatomic area of involvement: type I—Lisfranc pattern; type II—naviculocuneiform pattern; type III—perinavicular pattern; and type IV—transverse tarsal (Chopart) pattern. These investigators also introduced a clinical classification system based on the degree of deformity seen on physical examination while weight bearing. In stage A, the midtarsus was above the metatarsocalcaneal plane. In stage B, the midtarsus was coplanar with this plane. In stage C, the midtarsus was below this plane (**Fig. 3**). In 2002, Schon and colleagues[28] published an interobserver reliability and reproducibility study to validate the proposed radiographic classification. Seventy-five orthopedists were tested, and the system was found to be reliable, with lower error rates among foot and ankle subspecialists and residents.

The degree of deformity is also important in classifying Charcot midfoot neuroarthropathy, because standardized angular measurements tend to normalize when the foot dislocates through the midfoot. In cases in which the midfoot has dislocated, the anteroposterior and lateral first tarsometatarsal angles tend to decrease with increasing deformity because following dislocation, the foot would develop a "bayonet" configuration, with the first metatarsal and talus becoming parallel.

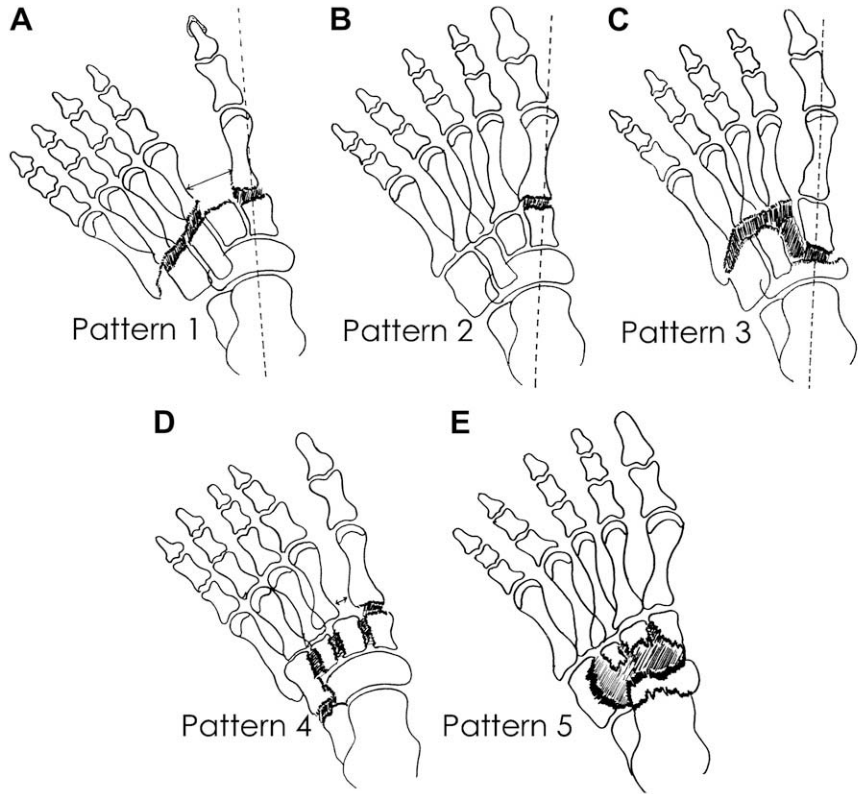

Fig. 1. Patterns of Charcot midfoot dislocation as described by Sammarco and Conti.[29] (*A*) Pattern 1: diastasis between the first and second metatarsals, with middle and lateral column dislocation/dissolution at the tarsometatarsal (TMT) joint. (*B*) Pattern 2: first TMT joint involvement only. (*C*) Pattern 3: medial column dislocation at the naviculocuneiform joint, with TMT joint dislocation of the middle and lateral columns. (*D*) Pattern 4: first TMT joint dislocation with first-second metatarsal diastasis, intercuneiform fragmentation, and extension to the calcaneocuboid joint. (*E*) Pattern 5: perinavicular arthropathy with distal intertarsal fragmentation and extension. (*From* Sammarco GJ, Conti SF. Surgical treatment of neuropathic foot deformity. Foot Ankle Int 1998;19:105; with permission. Copyright © 2009 by the American Orthopaedic Foot and Ankle Society.)

Sammarco and Conti[20] included a measurement of dorsal displacement to quantify the degree of midfoot deformity, and this measurement was better defined by Sammarco and colleagues[29] in a series of patients who underwent midfoot reconstruction for neuroarthropathic deformity. Dorsal displacement was measured on the lateral radiograph as the vertical distance between the axis of the talus and the axis of the first metatarsal at the level of the midfoot dislocation (**Fig. 4**). On the weight-bearing lateral radiograph, a line perpendicular to the floor was drawn at the apex of the deformity, the difference in height from the floor to the line was drawn down the central axis of the talus, and the central axis of the first metatarsal was measured. Schon and colleagues[28] classified the degree of deformity as type alpha or beta. A beta stage indicates more severe deformity and is assigned when one or more of the following criteria are met: (1) a dislocation is present, (2) the lateral first metatarsal angle is 30° or greater, (3) the lateral calcaneal-fifth metatarsal angle is 0° or greater, or (4)

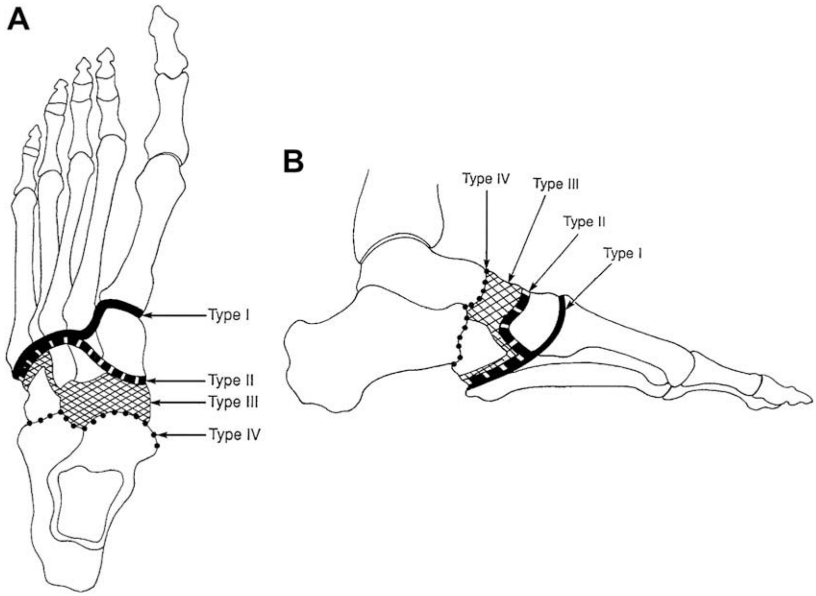

Fig. 2. Schon and colleague's[27] classification of diabetic midtarsus deformity is based on the anatomic area of involvement: type I—Lisfranc pattern; type II—naviculocuneiform pattern; type III—perinavicular pattern; and type IV—transverse tarsal (Chopart) pattern. (*A*) A/P weight bearing x-ray. (*B*) Lateral weight bearing x-ray. (*From* Schon LC, Weinfeld SB, Horton GA, et al. Radiographic and clinical classification of acquired midtarsus deformities. Foot Ankle Int 1998;19:397; with permission. Copyright © 2009 by the American Orthopaedic Foot and Ankle Society.)

the anteroposterior talar-first metatarsal angle is 35° or greater. Schon and colleagues[28] used standardized views with weight-bearing radiographs of the foot to determine the alpha-beta classification, using angular measurements described by Gould[30] and by Sangeorzan and colleagues.[31]

Sammarco and colleagues[29] recently used these classifications to evaluate the effectiveness of treatment in a series of patients treated with midfoot fusion and deformity correction for neuroarthropathy. In this series, patients who had Sammarco patterns 1 and 3 (Schon types 1 and 2) had better clinical results and fewer postsurgical complications. The high prevalence of the Schon beta designation and the significant amount of dorsal displacement in most patients indicated that the severity of deformity played a more important role in the decision for surgery than the anatomic pattern of involvement. Sammarco pattern 5 and Schon type 3 involve fragmentation of the navicular with involvement of the perinavicular joints, and required arthrodesis of the talonavicular joint in all cases and arthrodesis of the subtalar joint in two cases. Although successful results were eventually achieved, complications occurred in all seven of the Sammarco pattern 5/Schon type 3 deformities, with four patients suffering mechanical failure of the medial column fixation.

PREOPERATIVE MANAGEMENT

Preoperative assessment is of critical importance in achieving a successful clinical result. A thorough work-up for infection is necessary in many cases because the presence of osteomyelitis drastically changes the recommended treatment protocol. Many

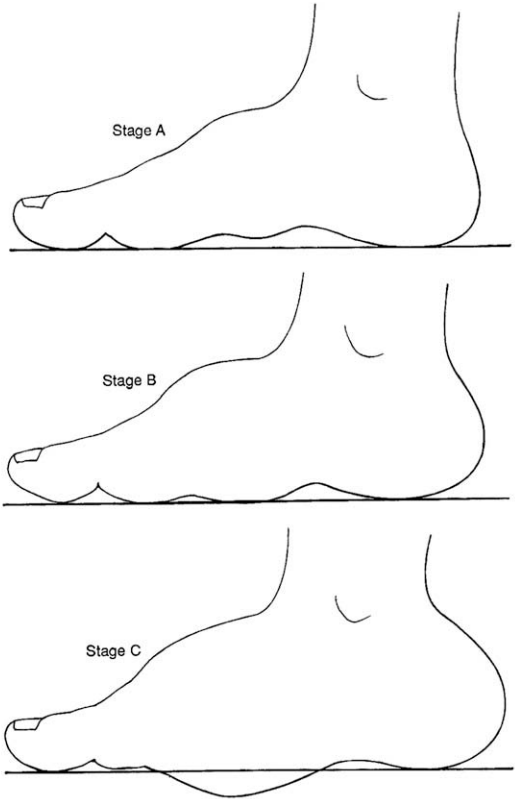

Fig. 3. Schon and colleague's[27] clinical stages of the degree of deformity are based on physical examination. In stage (A), the midtarsus is above the metatarsocalcaneal plane. In stage (B), the midtarsus is coplanar with this plane. In stage (C), the midtarsus is below this plane. (*From* Schon LC, Weinfeld SB, Horton GA, et al. Radiographic and clinical classification of acquired midtarsus deformities. Foot Ankle Int 1998;19:398; with permission. Copyright © 2009 by the American Orthopaedic Foot and Ankle Society.)

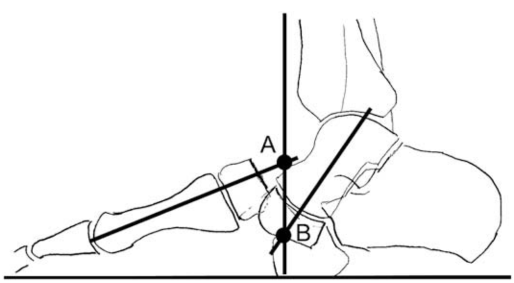

Fig. 4. The measurement of dorsal displacement in midfoot dislocation as described by Sammarco and colleagues.[29] The amount of dorsal displacement is the vertical distance measured between the midline of the lateral talar line at the level of dislocation (point B) and the midline of the lateral first metatarsal axis (point A) measured on weight-bearing radiographs. (*From* Sammarco VJ. Midtarsal arthrodesis in the treatment of Charcot midfoot arthropathy. J Bone Joint Surg Am 2009;91:80–91; with permission.)

Charcot patients present with Eichenolz stage I disease, and this can be difficult to differentiate from cellulitis and osteomyelitis. The scenario is often complicated because the patient may be seen after admission by the internal medicine service, which has placed the patient on bed rest with strict instructions to keep the foot elevated while simultaneously starting antibiotics. Diagnostic studies such as plain radiographs, MRI, and technetium bone scans have high false-positive rates for osteomyelitis in the acute setting, and the entire clinical setting needs to be evaluated carefully before developing a treatment plan. The author has found that MRI is of little utility in the work-up of neuroarthropathic patients. Plain radiographs combined with radionuclide imaging (with a dual-phase study or sequential technetium and labeled white blood cells scans) are of more utility and offer more specificity for infection. An in-depth discussion of the radiographic techniques used to clarify the presence or absence of infection in patients who have neuroarthropathy is beyond the scope of this article, and the reader is referred to reviews done by Lewis,[32] Lipman and colleagues,[33] and Timins[34] for further reading.

The author's current preoperative work-up includes optimization of all medical comorbidities, including diabetic control and cardiac function, using a team of medical specialists and the patient's primary care physician. All patients who do not have palpable pulses are sent for noninvasive vascular studies, and those who have poor vascularity are referred for revascularization, which may be done with endovascular or open techniques, depending on the severity of disease. Patients who do not have adequate vascular status and who cannot be revascularized are not considered candidates for reconstructive surgery or limb salvage.

Arthrodesis with the application of permanent internal fixation requires a sterile field. It is the author's opinion that sterility cannot be adequately obtained in the presence of ulcers or a deep infection without staged surgery. Wagner grades 1 and 2 ulcers can usually be resolved with the use of a total-contact cast and non–weight bearing. If the ulcers do not resolve with standard contact casting, local wound care, and medical/vascular optimization, then a higher suspicion of osteomyelitis should be present. Patients who are unable to resolve ulcers despite optimized medical treatment may not have adequate biologic resources to heal surgical wounds and arthrodesis procedures. These patients may be better served with primary amputation.

Cases in which neuroarthropathic foot deformity is combined with osteomyelitis represent a particularly difficult subset of patients. Patients in whom infection cannot be ruled out with standard imaging and radiographic criteria should undergo biopsy and are surgery planned accordingly. In patients who have neuropathic foot deformity combined with infection, limb salvage may be possible. If limb salvage is to be attempted, then a staged procedure is recommended, including aggressive debridement of infected bone and treatment with organism-specific antibiotics. Often, the author reduces the deformity during the initial surgery and stabilizes the extremity with an external fixator but does not apply permanent orthopaedic implants in this setting. When the osteomyelitis can be resolved, it may be possible to salvage the extremity with arthrodesis. Patients who have known osteomyelitis need to be counseled preoperatively of the need for multiple surgeries, a high rate of complications, and the potential need to proceed with amputation if the infection cannot be eradicated or if the infection is spreading proximally.

"SUPERCONSTRUCTS"

Neuropathic midfoot disease is inherently difficult to treat surgically. "Dissolution" of the bone in the area of fracture with resultant dislocation is one of the hallmarks of the disease process and is thought to be caused by sympathetic denervation and a resultant hyperemia. Bony dissolution, fragmentation, and osteoporosis increase the technical demands of midfoot reconstruction in neuropathic fractures. Earlier series reported recurrence of the deformity and nonunion as common sequelae of attempted arthrodesis. Standard fixation techniques using obliquely oriented lag screws are often inadequate due to the bony changes that accompany the Charcot process (**Fig. 5**). Poor bone quality, neuropathy, poor vascularity, and impaired nutrition of glycosylated tissue in diabetic patients all delay healing of the arthrodesis and contribute to complications. Patients are often overweight and inflexible and may find it difficult or impossible to comply with the non–weight bearing restrictions needed to achieve arthrodesis.

Evolving techniques have focused on increasing the stability of fixation primarily by extending fixation hardware proximally and distally into areas where the bone is not fragmented by the neuropathic process. Small-diameter crossed screws and pins are being replaced by larger, stronger fixation devices. Newer techniques do not depend on the poor bone in the area of dissolution for fixation but "bridge" this area by achieving fixation proximally and distally. Although this methodology sacrifices motion in otherwise normal joints, the stability of these constructs is dramatically improved.

The term *superconstruct* may be used to describe surgical techniques in which some normal principles of orthopaedic techniques are abandoned to improve stability and diminish the likelihood of failure of the procedure. A superconstruct is defined by four factors: (1) fusion is extended beyond the zone of injury to include joints that are not affected to improve fixation, (2) bone resection is performed to shorten the extremity to allow for adequate reduction of deformity without undue tension on the soft tissue envelope, (3) the strongest device is used that can be tolerated by the soft tissue envelope, and (4) the devices are applied in a position that maximizes mechanical function. Superconstructs are used in cases in which technical problems in achieving a successful surgical outcome are expected. Superconstructs are often performed in the settings of bone loss, dysvascular bone, major deformity correction, and severe osteoporosis, and in patients who have multiple medical comorbidities that make them high risk for poor surgical healing. These cases involve fusion of joints that are not involved in the area of pathology to improve the fixation of the construct.

Fig. 5. Lateral radiograph of failed midfoot reconstruction done with crossed small-diameter screws and one-third tubular plates applied dorsally and medially. Note the recurrence of deformity and mechanical failure of multiple implants.

A superconstruct often uses orthopaedic implants that are stronger than those normally used to achieve arthrodesis, and those implants may be placed in a manner that optimizes their mechanical advantage despite technical difficulties in using these techniques. This article discusses three evolving superconstruct methods of achieving correction and fusion in patients who have neuroarthropathic foot disease: plantar plating, locked plating, and axial screw fixation. These techniques are new, with limited data from the literature available for review.

Plantar Plating Techniques

Although the application of plates for fixation of midfoot fusions is not new, plating has been a popular method of fixation of fusions in patients who have Charcot midfoot disease. Plating allows the fixation to span the area of Charcot dissolution into areas of better-quality bone. When the plates are extended into the metatarsals, fixation can be placed into cortical bone, which usually has better density than the midfoot bones. Plating can also be used to add compression to the fusion site. Due to anatomic considerations and technical ease of placement, dorsal and medial applications of plate constructs have been the most common. Despite extension of the fusion into uninvolved and better bone, however, plate fixation alone does not seem to significantly improve union rates in neuropathic feet. Schon recognized that application of plates in a plantar location offered multiple mechanical advantages, despite technical difficulties in applying the device in this location (Schon LC, MD, personal communication, 1998). Schon developed the concept of plantar plating to improve the strength of the construct, noting that the plantar location would improve the intraoperative ability to achieve correction and place the device under tension during weight bearing (Schon LC, MD, personal communication, 1998). In a simulated midfoot fusion model, Marks and colleagues[35] showed that application of the plates plantarly was biomechanically more stable than crossed screws in stiffness and in load to failure. A similar study comparing plantar plate fixation with screw fixation for metatarsal osteotomies yielded similar results.[36] The construct yields superior strength by placing the plate along the tension side of the fusion mass (**Fig. 6**). Schon and colleagues[21] reported successful results using this technique in 34 patients who had severe midfoot neuroarthropathic disease that had failed conservative and other surgical measures. The author has found plantar plating techniques to produce reliable arthrodesis of neuropathic midfoot dislocation.

Locked Plating

The use of locked plates, which were developed as fixed-angle devices for fixation of long-bone fractures, has expanded almost exponentially over the past few years. These devices create a fixed-angle device by rigidly attaching the screw to the plate. These devices have the advantage of significantly improving fixation in osteoporotic bone.[37,38] For Charcot midfoot disease, these devices have many desirable traits. The fixed-angle device overcomes some of the difficulties of applying the plate plantarly. In theory, the locked plate has equivalent fixation to the plantar construct, without necessitating the extensile plantar exposure needed for the latter. In cases in which the talonavicular joint must be crossed, the author has found it difficult to apply any plate plantarly due to the sustentaculum tali of the calcaneus. A medial or dorsal plate can achieve excellent fixation in the talar neck without necessitating fusion of the subtalar joint (**Fig. 7**). The author is unaware of any published clinical series of Charcot disease being treated with locked plates for fixation, although the technique was presented at the American Academy of Orthopaedic Surgeons Specialty Day (V. James Sammarco, MD, unpublished data, 2008).

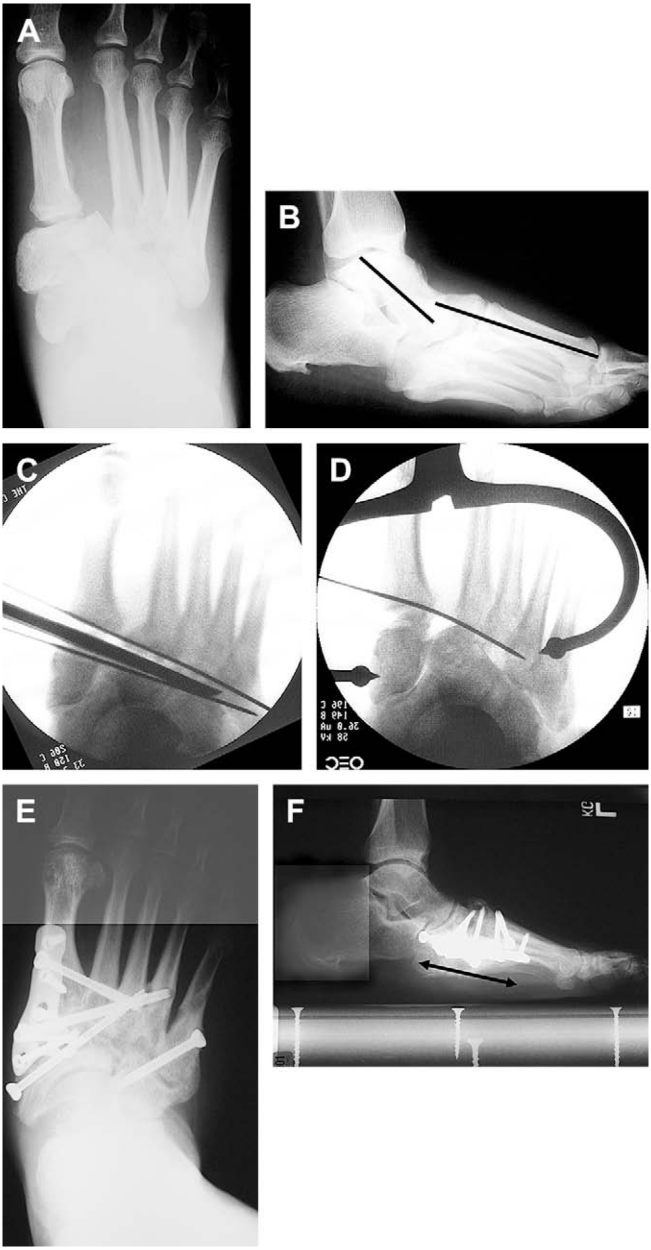

Fig. 6. A 36-year-old man who had diabetic neuropathy developed Charcot midfoot dislocation after a minor trauma and was treated with midfoot osteotomy and arthrodesis. (*A* and *B*) Preoperative radiographs. (*C* and *D*) Intraoperative fluoroscopy showing plantar medial resection of bone as described by Schon and colleagues.[21] (*E* and *F*) Two-year postoperative radiographs show solid fusion. Note that plantar plate is along tension side of fusion mass.

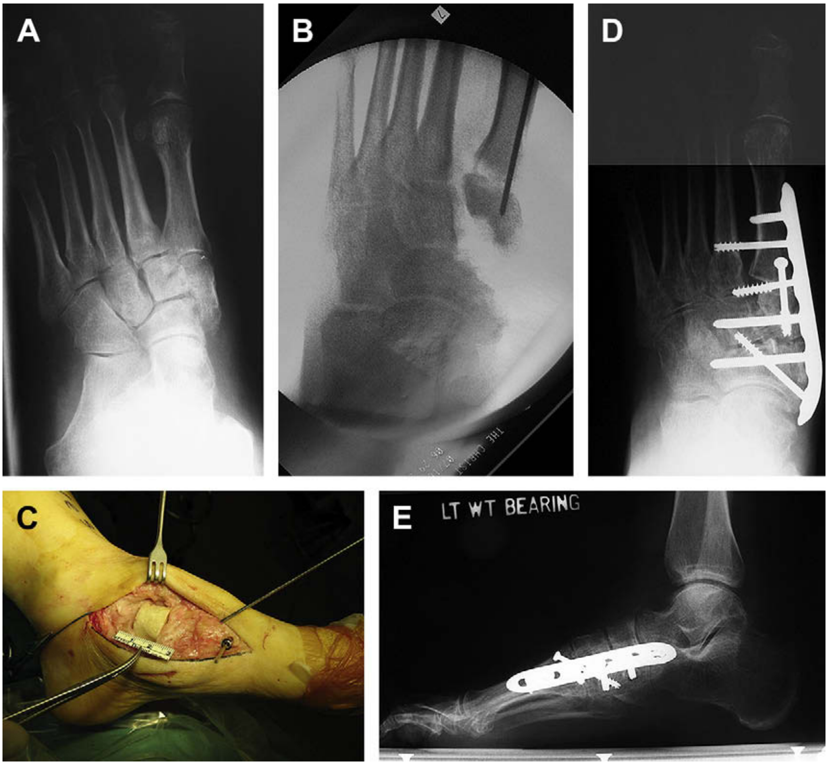

Fig. 7. A 48-year-old woman who had diabetes mellitus and sensory neuropathy developed an atraumatic dislocation of the medial column of her foot, with bony prominence and impending ulceration. (*A*) Preoperative anteroposterior radiograph shows Charcot dislocation of medial column at naviculocuneiform joint. (*B*) Intraoperative fluoroscopy demonstrates bony defect caused by dissolution of bone. (*C*) Allograft iliac crest graft is shaped to fit the defect. (*D* and *E*) Radiographs taken 18 months postoperatively show successful fusion with locking plate construct. The plate acts as a fixed-angle device and can be contoured to suit the anatomy.

Axial Screw Fixation

Axial screws as a superconstruct for midfoot reconstruction refers to passing long screws through the foot so that the distal portion of the screw lies in the intramedullary canal of the metatarsals. The screws can be applied antegrade (from the calcaneus or talus) or retrograde (through the metatarsophalangeal joints) (**Figs. 8** and **9**). The author knows of cases in which this technique was used over 20 years ago, and it is difficult to say where the technique originated. The first published case that the author is aware of was presented for reconstruction of a midfoot deformity in which a screw was passed from the calcaneus into the fourth metatarsal shaft.[39] Kann and colleagues[26] demonstrated that axial screw placement afforded better stability than an oblique screw in fusion of the calcaneocuboid joint.

The technique of applying multiple axial screws as fixation has several advantages. The first is that the placement and positioning of the screws aid in reduction of the deformity. Temporary fixation can be achieved with guide wires for cannulated screws, allowing the foot position and radiographs to be checked before application

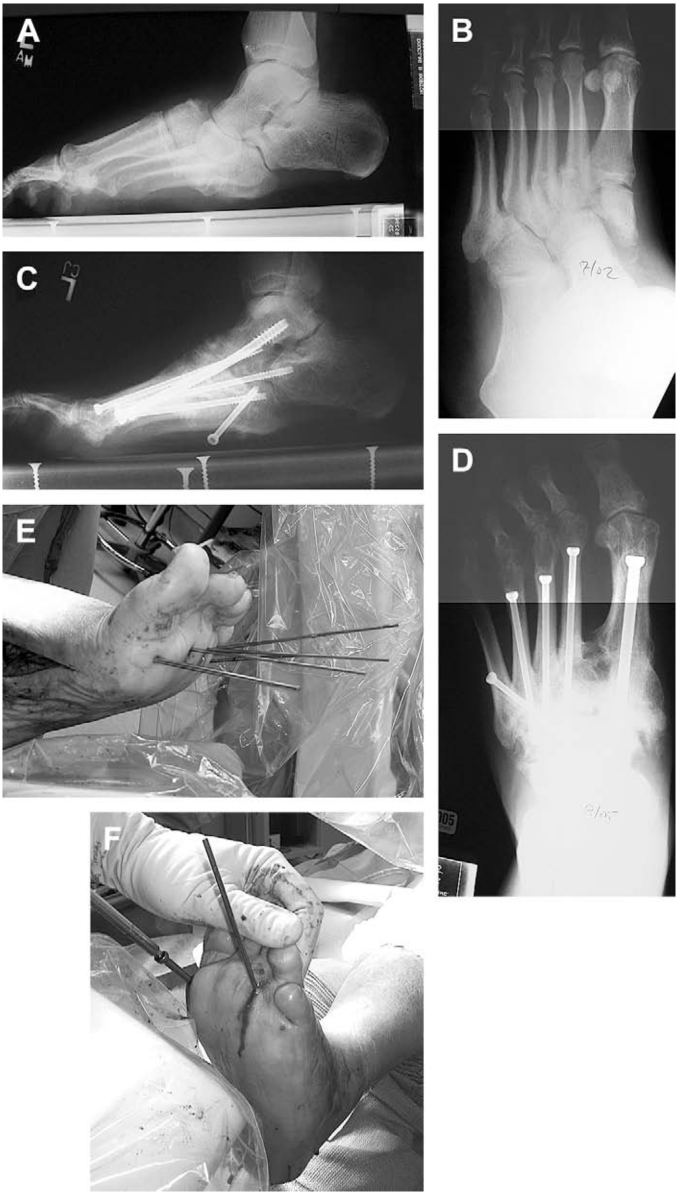

Fig. 8. This case demonstrates retrograde axial fixation of a midfoot fusion done for neuroarthropathy in a 54-year-old man who had diabetes mellitus. (*A* and *B*) Preoperative radiographs show dislocation through the midfoot. (*C* and *D*) Radiographs taken 3 years following surgery show successful fusion and good maintenance of reduction. (*E* and *F*) Screw insertion technique. The deformity is reduced and final positioning is temporarily achieved by passing guide wires for cannulated screws through the metarsophalangeal joints. Final positioning is then checked fluoroscopically. The metatarsal shafts are reamed with cannulated drills so that they will accept larger-diameter screws without shattering. Screws are applied through the metarsophalangeal joints and countersunk to the level of the distal metaphyseal-diaphyseal junction.

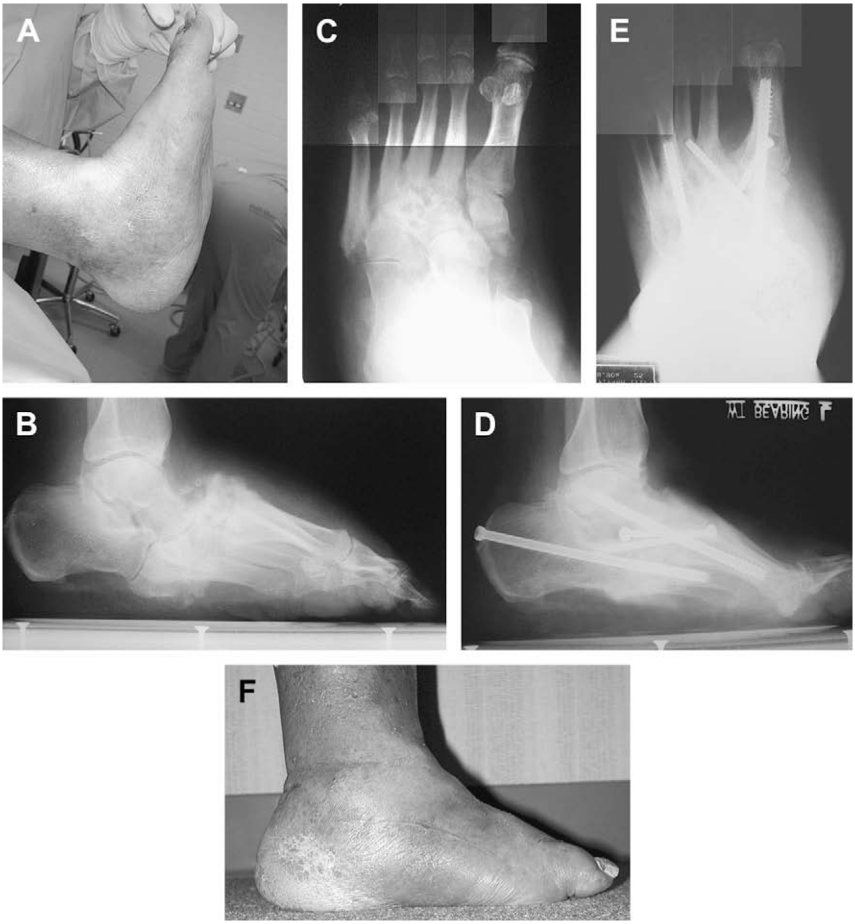

Fig. 9. This case demonstrates antegrade fixation of a midfoot fusion performed for neuroarthropathy in a 37-year-old man who had severe peripheral neuropathy and diabetes mellitus. (*A*) Preoperative clinical photograph shows Schon stage C rocker-bottom deformity. (*B* and *C*) Preoperative radiographs showing midfoot dislocation with "bayoneting" of the forefoot on the hindfoot. (*D* and *E*). Postoperative radiographs 26 months after midfoot fusion using antegrade intramedullary screws in the first and fourth metatarsals. (*F*) Postoperative clinical photograph shows restoration of the longitudinal arch and a plantigrade foot more than 2 years after surgery.

of the final fixation devices. Compression of the arthrodesis sites is accomplished by simply tightening the screws. The intramedullary positioning of the screws eliminates stress risers in the cortical bone of the metatarsals that occur from transcortical screws created with plates or oblique screws. In addition, the fusion procedures can be done through more limited incisions without the extensive stripping of bone necessary for the application of long plates. The screw position is entirely intraosseous, which diminishes concern for exposed hardware in the event of a wound complication.

Sammarco and colleagues[29] recently published a series of patients who had neuroarthropathic midfoot deformity treated with midfoot fusion using intramedullary screws for correction and fixation. Twenty-two patients were followed for an average 52 months (minimum 2 years' follow-up). The indications for surgery were recurrent ulcerations and gross instability that was not amenable to management with custom diabetic shoewear or a Charcot restraint orthotic walker. The patients had severe disease, and 20 of the 22 patients were classified as Schon type beta due to dislocation of the midfoot or severe angular deformity. Patients in whom the fusion crossed the talonavicular joint were at higher risk for complications and nonunion. At final follow-up, there were no amputations, and all patients were considered to have successful limb salvage.

SUMMARY

Management of Charcot deformity of the foot and ankle continues to challenge physicians. Medical comorbidity, peripheral neuropathy, vascular disease, and immune impairment cause severe problems for these patients and, when combined with neuroarthropathy, can lead to amputation. Progressive bony deformity and bone resorption, which may accompany neuroarthropathy, only increase the challenge of surgical treatment. These challenges have led physicians to develop superconstruct techniques whereby fusion is extended beyond the zone of injury to include joints that are not affected to improve fixation, bone resection is performed to shorten the extremity to allow for adequate reduction of deformity without undue tension on the soft tissue envelope, the strongest device is used that can be tolerated by the soft tissue envelope, and the devices are applied in a novel position that maximizes mechanical function. Large clinical series are lacking, but early reports of these new techniques are promising.

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