Radiographic Outcomes, Union Rates, and Complications Associated With Plantar Implant Positioning for Midfoot Arthrodesis

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Abstract

Background: Midfoot arthrodesis has long been successfully included in the treatment paradigm for a variety of pathologic foot conditions. A concern with midfoot arthrodesis is the rate of nonunion, which historically has been reported between 5% and 10%. Plantar plating has also been noted to be more biomechanically stable when compared to traditional dorsal plating in previous studies. Practical advantages of plantar plating include less dorsal skin irritation and the ability to correct flatfoot deformity from the same medial incision. The purpose of this study is to report the arthrodesis rate, the success of deformity correction, and the complications associated with plantar-based implant placement for arthrodesis of the medial column.

Methods: A retrospective review was undertaken of all consecutive patients between 2012 and 2019 that underwent midfoot arthrodesis with plantar-positioned implants. Radiographic outcomes and complications are reported on 62 patients who underwent midfoot arthrodesis as part of a correction for hallux valgus deformity, flatfoot deformity, degenerative arthritis, Lisfranc injury, or Charcot neuroarthropathy correction.

Results: Statistically significant improvement was seen in the lateral talus–first metatarsal angle (Meary angle) and medial arch sag angle for patients treated for flatfoot deformity correction. In patients treated for hallux valgus deformity, there was a reduction in the intermetatarsal angle from 15.4 to 6.8 degrees. The overall nonunion rate was 6.45% in all patients. The rate of nonunion was higher at the NC joint compared to the TMT joint and with compression claw plates. One symptomatic nonunion required revision surgery (1.7%). There were no nonunions when excluding neuroarthropathy patients and smokers. The odds ratio (OR) for nonunion in patients with neuroarthropathy was 6.05 (P < .05), and in active smokers the OR was 2.33 (P < .05).

Conclusion: Plates placed on the plantar bone surface for midfoot arthrodesis achieved and maintained deformity correction with rare instances of symptomatic hardware for a variety of orthopedic conditions. An overall clinical and radiographic union rate of 94% was achieved. The radiographic union rate improved to 100% when excluding both neuroarthropathy patients and smokers. The incidence of nonunion was higher in smokers, neuroarthropathy patients, naviculocuneiform joint fusions, use of compression claw plates, and when attempting to fuse multiple joints. Incisional healing complications were rarely seen other than in active smokers.

Level of Evidence: Level IV, case series.

Keywords: Lapidus, plantar plating, nonunion, tarsometatarsal, arthrodesis

Introduction

Multiple techniques for midfoot arthrodesis exist, including variations in implant fixation constructs, implant position placement, and operative approaches. Decreasing soft tissue irritation, increasing bone interface fixation, increasing

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overall construct strength, and decreasing nonunion rates are important factors in obtaining acceptable arthrodesis outcomes. 4,8,10,15,18,21,23 The nonunion rate at the midfoot—forefoot junction at the first tarsometatarsal (TMT) joint is commonly reported to be approximately 10%. 1,3,5,6,9,16,20,22 Anatomic cadaveric and biomechanical studies have examined plantar-based implant positioning of plates as an alternative to more traditional dorsally or medially positioned implants. 4,10,15,18,19,21,23 Placing implants and obtaining fixation along the plantar surface of the bone may create a tension band construct during physiologic loading that compresses the arthrodesis site to optimize stability and healing potential. Biomechanical studies support these theories and have shown increased fixation stiffness with plantar vs dorsal plating. 7,8,15-17 Additionally, utilization of plantar implant application for pes planus deformity correction may allow the surgeon to limit the number of incisions by addressing the tendon pathology, deltoid and spring ligaments, and midfoot joint sag with arthrodesis through a single medially based incision.

The purpose of this study was to report the arthrodesis rate, the success of deformity correction, and the complications associated with plantar-based implant placement for arthrodesis of the medial column. Multiple diagnostic indications are included in this consecutive case series including midfoot degenerative arthritis, hallux valgus deformity correction, planovalgus deformity correction, traumatic Lisfranc injury, and Charcot neuroarthropathy.

Material and Methods

Approval from the Institutional Review Board was obtained for a retrospective chart review that was conducted on all patients who underwent a midfoot arthrodesis by a foot and ankle fellowship-trained orthopedic surgeon at a single academic institution between the dates of January 1, 2012, and December 31, 2019. Inclusion criteria for the study were age ≥ 18 years while undergoing single or multiple midfoot arthrodesis procedures. Average patient age was 51.4 years with age ranges from 18 to 75 years. Patients were identified using midfoot fusion CPT codes 28740, 28730, 28735, or correction of a hallux valgus deformity with Lapidus procedure CPT code 28297. Patients were included if arthrodesis procedures had a plate construct located on the plantar bone surface of the medial column and had postoperative clinical follow-up of at least 12 months with complete weightbearing preoperative and postoperative radiographic imaging series. Patients were selected for plantar plating based on surgeon discretion as well as the need for TMT fusion and concomitant procedures.

Demographic data were evaluated by one board-certified foot and ankle attending and one foot and ankle fellow and reported including patient age, binary smoking status, diabetes, Charcot neuroarthropathy, and other medical comorbidities. All patients were followed until union was achieved or clinical improvement was satisfactory to the patient, and no further operative intervention was warranted. Routine follow-up radiographs were obtained at 2 weeks, 6 weeks, 3 months, and 6 months, postoperatively. Two evaluators independently reviewed all radiographic imaging for maintenance of implant position, angular deformity correction, and bony union rate. Successful arthrodesis was defined by bone bridging of 3 cortices with the dissolution of visible joint space on orthogonal radiographs. Other documented radiographic parameters to evaluate arthrodesis site healing included absence of lucency, maintained implant position, and lack of halo effect at the screw-bone interface on weight-bearing radiographs. In patients treated for a flatfoot deformity, the Meary angle and medial arch sag angle were compared on preoperative and postoperative images to obtain the magnitude of radiographic correction. In patients treated for hallux valgus deformity, the intermetatarsal angle was used to establish the magnitude of deformity correction. Serial weightbearing radiographs were independently evaluated for malunion, nonunion, or hardware migration. Secondary outcome measures included reoperation rate, concomitant procedures, wound complications, infections, failure of clinical progression, and other reported complications.

Statistical analysis comparing preoperative and postoperative radiographic measurements was performed. The analysis involved descriptive analysis of demographic, injury-related characteristics, operative management, and primary/secondary outcomes. Data between patients with nonunion vs those with union were compared. Student t test was used to compare continuous data, including social demographics, number of spanned joints, number of procedures performed, and comorbidities present. Chi-squared analysis was used to compare categorical data such as the presence or absence of comorbidities. Statistical significance was defined at the 5% (P < .05) level. All statistical analyses were conducted using the statistical package R (www.r-project.org).

Operative Procedure

The midfoot fusion procedure was often performed in conjunction with other procedures to address the inherent pathology. The operative sequence would routinely begin with gastrocnemius lengthening when indicated by a positive Silversköld test. A calcaneal slide vs subtalar fusion would often be performed based on the clinical rigidity of the hindfoot and presence of arthritis on preoperative imaging. The posterior tibial tendon would next be evaluated for tears, tissue quality, and excursion in order to determine the need for repair, advancement, or FDL transfer. 5 Regarding the midfoot fusion, a medial-based operative approach was centered over the first tarsometatarsal (TMT) joint to perform arthrodesis of the joint. The dorsoplantar location of the incision was based at the junction of the plantar and middle one-third of the foot. Careful dissection was performed through the skin and subcutaneous tissue, with the
primary saphenous neurovascular structures most commonly retracted dorsally.\textsuperscript{14} Release of the dorsal, medial, and plantar capsular structures allowed complete visualization and distraction of the joint. The distalmost attachment of the tibialis anterior tendon on the first metatarsal was released in line with the capsulotomy. The primary tendinous attachments of the tendon to the medial cuneiform were preserved as the tendon was retracted proximally.\textsuperscript{14} Joint preparation was performed with excision of the cartilage and sclerotic bone by chisels, curets, or a TPS saw (Stryker, Kalamazoo, MI), followed by spatial positioning, bone grafting, and compression of the fusion surfaces. The joint was temporarily held reduced with a clamp, a Kirschner (K)-wire, or a screw, while plate fixation was obtained on the plantar surface of the bone. The plate was fixated to the metatarsal bone first, followed by further compression and fixation into the medial cuneiform bone. Deep fascial layers were closed over the plate with independent sutures to reinforce the distal reflection of the tibialis anterior tendon to the fascial tissue sleeve and to any preserved tendinous footprint on the first metatarsal base. If the naviculocuneiform (NC) joint was fused, a similar incision and joint debridement was performed from a medial-based approach centered more posteriorly, with the tibialis anterior tendon retracted dorsally and distally at the NC joint. Local graft or proximal tibia autograft was used for all fusions and occasionally mixed with demineralized bone matrix (DBM) when volume expansion was necessary (Figures 1-4).

**Postoperative Protocol**

Patients were placed into a well-padded short leg splint in the operating room that remained in place for 2 weeks. Sutures were removed at 2-3 weeks, and patients were placed into a removable boot to allow for bathing and range of motion at the ankle. They were instructed to remain nonweightbearing on the forefoot with weightbearing through the heel for transfers only. At 6 weeks postoperation, patients were allowed to weightbear in the boot with a more natural gait and transitioned into a regular shoe as comfort allowed.

**Results**

Sixty-two patients met inclusion criteria (Table 1). Clinical follow-up averaged 36.2 months (range, 16-66 months). The first TMT joint was fused in 43 patients, and the NC joint was fused in 23 patients. This included 5 patients who had fusion of the first TMT and NC joints, simultaneously. Two patients underwent arthrodesis of the talonavicular (TN) joint, with one of these patients having concomitant arthrodesis of the TN and NC joints simultaneously.

Forty-five patients underwent midfoot arthrodesis as part of a flatfoot correction, 3 patients as part of a hallux valgus deformity correction, 6 patients as part of a combined flatfoot and hallux valgus deformity correction, 4 patients for midfoot degenerative arthritis, 3 patients as part of a Charcot neuropathic deformity correction, and 1 patient for a displaced Lisfranc injury. The majority (47/62; 75\%) of patients received autograft alone, with the rest of the cohort (15/62; 25\%) receiving autograft plus augmentation with DBM. DBM was used at surgeon’s discretion when autograft harvest yielded unsatisfactory quality or quantity of bone for the necessary correction. Of the 4 nonunions, 2 patients had autograft alone, and 2 patients had autograft plus DBM.

In those patients undergoing an isolated flatfoot deformity correction or flatfoot in addition to hallux valgus deformity correction, an improvement in Meary angle from −18.2 preoperatively to +2.8 postoperatively was observed (21-degree change, $P < .01$). The medial arch sag angle in this group also showed significant improvement from −14.9 preoperatively to +2.3 postoperatively, an average overall
correction of 17.2 degrees ($P < .01$). In patients undergoing either isolated hallux valgus deformity corrections or hallux valgus corrections in addition to flatfoot deformity correction, intermetatarsal angle improved from $+15.4$ preoperatively to $+6.8$ postoperatively, an average overall correction of 8.6 degrees ($P < .01$) (Table 2).

The nonunion rate for all patients was 6.45% (4 of 62). Two of the 4 nonunions were in patients with Charcot neuroarthropathy (odds ratio [OR] 6.05, 95% confidence interval [CI] 0.6-20.03, $P < .05$). There were a total of 4 Charcot neuroarthropathy patients in the cohort, 2 of whom went on to successful union; thereby, a 50% union rate was achieved.

**Figure 2.** Preoperative anteroposterior radiograph.

**Figure 3.** Postoperative lateral radiograph.
in Charcot neuroarthropathy patients (Table 3). Both Charcot nonunion patients had attempted fusion of both the NC and first TMT joints, simultaneously. One of the Charcot nonunions had broken hardware with collapse that remained asymptomatic. This was closely followed with eventual malunion of both the NC and TMT joints at 1 year postoperation that did not require further intervention. The second Charcot nonunion patient eventually developed lateral column collapse and ulceration with osteomyelitis remote to the operative site, which ultimately led to a below-the-knee amputation. Overall, patients who had neuroarthropathy had an increased nonunion risk with an OR of 6.05 compared to patients with no Charcot diagnosis.

Excluding patients with Charcot neuroarthropathy, the nonunion rate was 3.3% (2 of 60). The 2 patients with non-Charcot nonunions both were active smokers. One of these patients was a 1.5-pack-per-day smoker who had attempted TN and NC joint fusion and remained clinically asymptomatic and radiographically stable at 3-year follow-up. The final nonunion patient was a 2-pack-per-day active smoker with a compression claw plate placed at the site of an isolated NC fusion. The patient underwent revision arthrodesis (overall revision rate, 1.6%) with a bone stimulator and vitamin D supplementation. Postoperative follow-up at 1.5 years after revision arthrodesis demonstrated complete radiographic union. Patients who were actively smoking at the time of procedure had an OR of 2.33 for increased chance of nonunion compared with non-smokers. (OR 2.33, 95% CI 0.3-17.88, \( P < .05 \)). There were 20 active smokers in the cohort, and the overall union rate in smokers was 90%.

There were no nonunions in the isolated TMT joint arthrodesis group. All 4 nonunions occurred in patients having the NC joint included in the overall arthrodesis construct (Table 4). One of these nonunions was an isolated NC joint fusion, one was a combined NC and TN fusion, and 2 were combined NC and first TMT fusions.

Hardware loosening and failure occurred in all patients with nonunion but loosening or failure did not always lead to nonunion. Seven of 34 (20.5%) patients had implant fracture of the arms of the compression claw plate. However, 4 of these progressed to bony union without significant loss of reduction on final weightbearing radiographs. Three of the 4 total nonunions were associated with compression claw plating (OR 2.61, 95% CI 0.26-26.62, \( P < .05 \)). There were no instances of hardware failure in 28 feet using an anatomically contoured plantar-specific plate. Two patients (2/62, 3.2%) chose to have hardware removed: one being a symptomatic compression claw plate and the other being an anatomic plantar-specific plate that the patient requested to be removed at the time of an unrelated procedure.

Figure 4. Postoperative anteroposterior radiograph.
| Patient No. | Sex   | Diagnosis                                             | Plate | Joint                          | Smoker | Union | ROH | Other Complications                                                                 |
|------------|-------|-------------------------------------------------------|-------|--------------------------------|--------|-------|-----|--------------------------------------------------------------------------------------|
| 1          | Male  | Flatfoot                                              | Claw  | NC                             | Yes    | Yes   | No  |                                                                                      |
| 2          | Female| Flatfoot, osteochondral lesion of the talus           | Claw  | NC                             | Yes    | Yes   | No  |                                                                                      |
| 3          | Male  | Flatfoot                                              | Claw  | First TMT, intercuneiform      | Yes    | Yes   | No  |                                                                                      |
| 4          | Female| Flatfoot                                              | Claw  | First TMT                      | No     | Yes   | No  |                                                                                      |
| 5          | Female| Flatfoot, ball and socket ankle                       | Anatomic | First TMT, 1-2 MT             | Yes    | Yes   | No  | Lateral ulcer leading to BKA 9 mo postop                                              |
| 6          | Male  | Charcot                                               | Anatomic | NC, first TMT                 | No     | No    | No  |                                                                                      |
| 7          | Female| Flatfoot                                              | Claw  | TMT                            | Yes    | Yes   | No  |                                                                                      |
| 8          | Female| Flatfoot                                              | Anatomic | TMT                           | No     | Yes   | No  |                                                                                      |
| 9          | Male  | Flatfoot, NC and ankle arthritis                      | Claw  | NC, first TMT                  | No     | Yes   | No  | Asymptomatic broken plate subsequent total ankle arthroplasty with talar subsidence/pain with final procedure of TTC fusion nail |
| 10         | Female| Flatfoot                                              | Claw  | NC                             | No     | Yes   | No  |                                                                                      |
| 11         | Male  | Flatfoot, hallux valgus deformity, midfoot arthritis  | Anatomic | First TMT                      | No     | Yes   | No  |                                                                                      |
| 12         | Female| Hallux valgus deformity                               | Anatomic | First TMT, 1-2 IM             | No     | Yes   | No  |                                                                                      |
| 13         | Male  | Flatfoot                                              | Claw  | First TMT, 1-2 IM             | No     | Yes   | No  | Local wound care                                                                     |
| 14         | Female| Flatfoot                                              | Claw  | NC                             | Yes    | Yes   | No  |                                                                                      |
| 15         | Male  | Flatfoot-tethered cord                                | Anatomic | First TMT                      | No     | Yes   | No  |                                                                                      |
| 16         | Female| Chronic Lisfranc                                      | Anatomic | First TMT, second TMT, 1-2 IM | No     | Yes   | No  |                                                                                      |
| 17         | Female| Midfoot arthritis, previous NC nonunion               | Claw  | NC, intercuneiform             | No     | Yes   | Yes | Patient request removal of hardware, while asymptomatic undergoing surgery on contralateral extremity |
| 18         | Male  | Flatfoot                                              | Claw  | NC                             | No     | Yes   | No  |                                                                                      |
| 19         | Male  | Flatfoot                                              | Claw  | NC                             | No     | Yes   | No  |                                                                                      |
| 20         | Male  | Flatfoot                                              | Anatomic | First TMT, second TMT, 1-2 IM | No     | Yes   | No  |                                                                                      |
| 21         | Female| Flatfoot + midfoot arthritis                          | Claw  | NC, intercuneiform             | No     | Yes   | No  | Broken hardware                                                                     |
| 22         | Male  | Flatfoot, subtalar and midfoot arthritis, first TMT nonunion | Anatomic | First TMT                      | No     | Yes   | No  |                                                                                      |
| 23         | Female| Flatfoot, hallux valgus deformity, midfoot and subtalar arthritis | Anatomic | First TMT, 1-2 IM             | Yes    | Yes   | No  | Local wound care                                                                     |
| 24         | Male  | Flatfoot, anterior impingement, TN and NC arthritis   | Claw  | TN, NC                         | Yes    | No    | No  | Local wound care                                                                     |
| 25         | Female| Flatfoot, midfoot arthritis                           | Anatomic | First TMT                      | Yes    | Yes   | No  |                                                                                      |
| 26         | Female| Flatfoot                                              | Claw  | NC                             | No     | Yes   | No  | Broken hardware                                                                     |
| 27         | Female| Flatfoot                                              | Anatomic | NC, TMT, 1-2 IM              | No     | Yes   | No  |                                                                                      |
| 28         | Female| Flatfoot, hallux valgus deformity                     | Claw  | First TMT, 1-2 IM             | Yes    | Yes   | Yes | Symptomatic hardware with stable fusion on radiograph                                |
| 29         | Male  | Cavovarus, subtalar and midfoot arthritis             | Claw  | TN                             | Yes    | Yes   | Yes | I&D with split-thickness skin graft                                                  |
| 30         | Female| Flatfoot, hallux valgus deformity                     | Anatomic | First TMT, Intercuneiform    | No     | Yes   | No  |                                                                                      |
| 31         | Female| Flatfoot                                              | Claw  | First TMT                      | No     | Yes   | No  |                                                                                      |
| 32         | Male  | Flatfoot                                              | Anatomic | First TMT, 1-2 IM            | No     | Yes   | No  |                                                                                      |

(continued)
| Patient No. | Sex  | Diagnosis                                 | Plate  | Joint                        | Smoker | Union | ROH  | Other Complications                      |
|------------|------|-------------------------------------------|--------|------------------------------|--------|-------|------|------------------------------------------|
| 33         | Female | Flatfoot, hallux valgus deformity         | Anatomic | First TMT                   | Yes    | Yes   | No   | Local wound care                         |
| 34         | Male  | Flatfoot, ankle and midfoot arthritis     | Anatomic | First TMT                   | No     | Yes   | No   |                                          |
| 35         | Male  | Midfoot arthritis                         | Claw  | NC, first TMT, second TMT, 1-2 IM, intercuneiform | No     | Yes   | No   |                                          |
| 36         | Female | Flatfoot                                 | Claw  | First TMT, intercuneiform, 1-2 IM | No     | Yes   | No   |                                          |
| 37         | Female | Flatfoot                                 | Anatomic | NC                         | No     | Yes   | No   |                                          |
| 38         | Female | Flatfoot, midfoot arthritis               | Claw  | NC                          | Yes    | No    | Yes  | Broken hardware with collapse           |
| 39         | Female | Flatfoot                                 | Claw  | NC                          | No     | Yes   | No   |                                          |
| 40         | Female | Flatfoot                                 | Anatomic | First TMT                   | Yes    | Yes   | No   |                                          |
| 41         | Male  | Flatfoot, midfoot arthritis               | Anatomic | First TMT, 1-2 IM           | No     | Yes   | No   |                                          |
| 42         | Female | Charcot, TMT dislocation                  | Anatomic | First TMT, second TMT, intercuneiform | No     | Yes   | No   |                                          |
| 43         | Male  | Flatfoot                                 | Claw  | NC                          | No     | Yes   | No   |                                          |
| 44         | Male  | Flatfoot                                 | Anatomic | NC                         | No     | Yes   | No   |                                          |
| 45         | Female | Flatfoot                                 | Claw  | First TMT, 1-2 IM           | No     | Yes   | No   |                                          |
| 46         | Female | Flatfoot                                 | Anatomic | First TMT                   | No     | Yes   | Yes  | Patient request removal of hardware, while asymptomatic undergoing surgery on contralateral extremity |
| 47         | Female | Flatfoot                                 | Anatomic | First TMT                   | No     | Yes   | No   |                                          |
| 48         | Female | Flatfoot                                 | Anatomic | First TMT                   | No     | Yes   | No   |                                          |
| 49         | Female | Flatfoot                                 | Claw  | NC                          | Yes    | No    | Yes  | Broken hardware                          |
| 50         | Female | Flatfoot                                 | Claw  | First TMT, 1-2 IM           | Yes    | Yes   | No   |                                          |
| 51         | Male  | Hallux valgus deformity                   | Claw  | First TMT                   | No     | Yes   | No   |                                          |
| 52         | Female | Hallux valgus deformity, midfoot arthritis | Claw  | First TMT, second TMT       | No     | Yes   | No   |                                          |
| 53         | Female | Flatfoot, midfoot nonunion, Charcot       | Claw  | NC, first TMT               | No     | No    | No   | Broken hardware                          |
| 54         | Female | Midfoot arthritis, Charcot                | Anatomic | First TMT                   | No     | Yes   | No   | Local wound care                         |
| 55         | Female | Flatfoot                                 | Claw  | NC                          | No     | Yes   | No   |                                          |
| 56         | Female | Flatfoot, hypermobility of first ray      | Claw  | First TMT, 1-2 IM           | Yes    | Yes   | No   |                                          |
| 57         | Female | Flatfoot, hypermobility of first ray      | Anatomic | First TMT, 1-2 IM           | Yes    | Yes   | Yes  | I&D with split-thickness skin graft       |
| 58         | Female | Flatfoot + midfoot arthritis              | Claw  | First TMT, 1-2 IM, Intercuneiform | No     | Yes   | No   |                                          |
| 59         | Male  | Flatfoot + midfoot arthritis              | Anatomic | First TMT                   | Yes    | Yes   | No   | Local wound care                         |
| 60         | Male  | Flatfoot + midfoot arthritis              | Claw  | NC                          | No     | Yes   | No   |                                          |
| 61         | Female | Flatfoot + midfoot arthritis              | Claw  | First TMT                   | No     | Yes   | No   |                                          |
| 62         | Female | Flatfoot + midfoot arthritis              | Anatomic | First TMT                   | Yes    | Yes   | No   | Local wound care                         |

Abbreviations: 1-2 IM, first-second intermetatarsal; BKA, below-the-knee amputation; I&D, irrigation and debridement; NC, naviculocuneiform; ROH, removal of hardware; TMT, tarsometatarsal; TN, talonavicular; TTC, tibiotalocalcaneal.
Seven (11.3%) patients, 6 of whom were smokers, had delayed wound healing that resolved with self-administered wound care or oral antibiotics. Two (3.2%) active smokers required operative debridement due to edge necrosis at the incision site, and one of these patients also had a BMI of 43. Both patients progressed to successful fusion, yet had their hardware removed at the time of debridement and split-thickness skin grafting. Overall, 8 of 9 wound complications occurred in smokers.

Discussion
This represents the largest consecutive series of patients undergoing plantar-positioned orthopedic implant placement for midfoot fusion. The nonunion rate for all patients with medial column fusion was 6.45% (4 of 60). Excluding patients with Charcot neuroarthropathy, the nonunion rate was 3.3% (2 of 60). These results are comparable to historical reports of dorsally based implant placement for midfoot fusion. TMT joint arthrodesis for correction of hallux valgus deformity and planovalgus deformity has variably reported nonunion rates from 5% to 15%.

Table 2. Radiographic Measurements.

| Angles Measured         | Preoperative Average | Postoperative Average | Average Change | P Value |
|-------------------------|----------------------|-----------------------|----------------|---------|
| Meary angle             | -18.2                | +2.8                  | 21             | <.01    |
| Medial arch sag angle   | -14.9                | +2.3                  | 17.2           | <.01    |
| Intermetatarsal angle   | +15.4                | +6.8                  | 8.6            | <.01    |

Table 3. Charcot Neuroarthropathy Patients.

| Patient | Sex | Diagnosis                          | Plate | Joints Fused                        | Smoker | Union | ROH | Other Complications                                                                 |
|---------|-----|------------------------------------|-------|------------------------------------|--------|-------|-----|------------------------------------------------------------------------------------|
| 6       | Male| Charcot                            | Lapidus| NC, first TMT                       | No     | No    | No  | Lateral ulcer leading to BKA 9 mo postoperation                                    |
| 42      | Female| Charcot, TMT dislocation          | Lapidus| First TMT, second TMT, intercuneiform | No     | Yes   | No  |                                                                                   |
| 53      | Female| Flatfoot, midfoot nonunion, Charcot| DC    | NC, first TMT                       | No     | No    | No  | Broken hardware, asymptomatic and 1-year postoperative follow-up stable radiographs |
| 54      | Female| Midfoot arthritis, Charcot        | Lapidus| First TMT                          | No     | Yes   | No  | Wound dehiscence healed with local wound care                                      |

Table 4. Nonunion Patients.

| Patient | Sex | Diagnosis                          | Plate | Joint       | Smoker | Union | ROH | Other Complications                                                                 |
|---------|-----|------------------------------------|-------|-------------|--------|-------|-----|------------------------------------------------------------------------------------|
| 6       | Male| Charcot                            | Lapidus| NC, first TMT | No     | No    | No  | Lateral ulcer leading to BKA 9 mo postoperation                                    |
| 24      | Male| Flatfoot, anterior impingement, TN and NC arthritis | DC    | TN, NC | Yes | No    | No  | Wound dehiscence healed with local wound care, broken hardware, asymptomatic at 32 mo |
| 38      | Female| Flatfoot, midfoot arthritis        | DC    | NC         | Yes    | Yes   | No  | Broken hardware with collapse, revision arthrodesis stable at 1.5-y follow-up       |
| 53      | Female| Flatfoot, midfoot nonunion, Charcot| DC    | NC, first TMT | No | No    | No  | Broken hardware, asymptomatic and 1-y postoperative follow-up stable radiographs    |

Abbreviations: BKA, below-the-knee amputation; DC, dynamic compression; NC, naviculocuneiform; ROH, removal of hardware; TMT, tarsometatarsal.

Smaller case series of outcomes with plantar plating have been reported in the past. Gutteck reported on 29 patients.
with 30 feet that underwent a Lapidus procedure for hallux valgus deformity correction using plate fixation on the plantar surface of the first TMT joint. After excluding those with previous foot and ankle surgery within the last 12 months, neuropathy, or rheumatoid arthritis, the incidence of wound complications was 10%. The study did not report on union rates specifically. In a separate publication, the same authors reported on plantar-based plating with immediate vs delayed weightbearing at 6 weeks. \cite{12,13} Thirty-four patients were included in the study, with 17 patients in each arm, and no nonunions were reported. There was no significant difference in wound complications between the 2 groups. The immediate weightbearing group was able to return to work 3.5 weeks earlier.

Plantar plating for first TMT joint stabilization has also been reported. Klos\cite{16} reported on 59 feet treated with a plantar-based plate and independent lag screw for hallux valgus deformity correction associated with first-ray hypermobility. The union rate in the study group was 98.3%. Two patients had wound complications (3.45%), with one going on to deep infection. The authors reported one case of tibialis anterior tendon rupture that was repaired with a turndown flap at 3 weeks postoperatively.

There are limitations within the current reported study design including its retrospective nature. All consecutive patients who underwent plantar-positioned implants for arthrodesis of the midfoot were evaluated, yet there was a considerable variability in diagnosis and degree of deformity. Implant selection and operative approach was also at the discretion of the treating surgeon. By nature of study design and operative approach, the cohort is isolated to medial column arthrodesis. Outcomes may differ from prior midfoot arthrodesis study groups that included intermediate column fusions, which inherently may be more stable based on anatomy. A control group undergoing dorsal plating for the same indications with similar comorbidities would also further strengthen any findings. Arthrodesis at the TMT joint was successful in all cases, although some patients had simultaneous fusion of the 1-2 intermetatarsal joint or the intercuneiform joint. The NC joint was always the site of nonunion. Given the relatively low numbers of subsets, it is difficult to draw definitive conclusions on the location or the effect of single-vs multiple-joint arthrodesis.

**Conclusion**

Plates placed on the plantar bone surface for midfoot arthrodesis achieved and maintained deformity correction with rare instances of symptomatic hardware for a variety of orthopedic conditions. Overall, the clinical and radiographic union rate was 94%. The union rate improved to 97% when excluding neuroarthropathy patients and improved to 100% when excluding both neuroarthropathy patients and smokers. The risk of nonunion appeared to be significantly higher in active smokers, patients with neuroarthropathy, with the utilization of compression claw plates, and when attempting to fuse multiple joints concomitantly. The rate of nonunion was higher at the NC joint vs the TMT joint. Incisional healing complications were rare except for in active smokers.

**Declaration of Conflicting Interests**

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**Ethics Approval**

Ethical approval for this study was obtained from UT Health Science Center - Chattanooga IRB.

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