Article

AMERICAN ORTHOPAEDIC FOOT & ANKLE SOCIETY

Foot & Ankle Orthopaedics
2021, Vol. 6(3) 1-10
© The Author(s) 2021
DOI: 10.1177/24730114211027115
journals.sagepub.com/home/fao

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

Tyler W. Fraser, MD[1], Daniel T. Miles, MD[1], Neal Huang, MD[1], Franklin B. Davis, MD[1], Burton D. Dunlap, MD[1], and Jesse F. Doty, MD[2]

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

[1] The University of Tennessee College of Medicine Chattanooga, Department of Orthopaedic Surgery, Chattanooga, TN, USA
[2] Erlanger Health System, Chattanooga, TN, USA

Corresponding Author:
Burton Dunlap, MD, University of Tennessee at Chattanooga, 975 E Third St, Chattanooga, TN 37403, USA.
Email: bdunlap736@gmail.com

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).

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 weightbearing 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 Silverskröld 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.[2] 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

Figure 1. Preoperative lateral radiograph.

primary saphenous neurovascular structures most commonly retracted dorsally.[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.[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 neuroarthropathy 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

Figure 2. Preoperative anteroposterior radiograph.

Figure 3. Postoperative lateral radiograph.

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 4. Postoperative anteroposterior 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 nonsmokers. (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.

Table 1. Patient Data.

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	
6	Male	Charcot	Anatomic	NC, first TMT	No	No	No	Lateral ulcer leading to BKA 9 mo postop
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	Anatomic	First TMT	No	Yes	No	
12	Female	Hallux valgus deformity, midfoot arthritis	Anatomic	First TMT, 1-2 IM	No	Yes	No	
13	Male	Flatfoot	Claw	First TMT, 1-2 IM	No	Yes	No	
14	Female	Flatfoot	Claw	NC	Yes	Yes	No	Local wound care
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)

Table 1. (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	Yes	No	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.

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

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

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	No	Yes	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; TN, talonavicular.

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%.[1,3,5,6,9,16,20,22] The reported nonunion rates of NC joint arthrodesis are also quite variable and range from 5% for isolated NC fusion and up to 15% for combined NC and TMT joint fusion. Acceptable rates of deformity correction were also achieved in those treated for hallux valgus and flatfoot deformities. There were significant improvements in the intermetatarsal angle, the medial arch sag angle, and Meary angle at an average follow-up duration of 36.2 months. There were no subjective complaints of tibialis anterior tendon irritation nor any clinical weakness noted on follow-up. Additionally, there were no instances of tendon rupture.

Smaller case series of outcomes with plantar plating have been reported in the past. Gutteck[11] 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.[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[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

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Jesse Doty, MD, reports personal fees from Arthrex Inc, personal fees from Globus Medical Inc, personal fees from Wright Medical Inc, outside the submitted work. ICMJE forms for all authors are available online.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Tyler Fraser, MD, https://orcid.org/0000-0003-1309-7916
Burton Dunlap, MD, https://orcid.org/0000-0001-5995-2135
Daniel T. Miles, MD, https://orcid.org/0000-0002-7173-6192

Ethics Approval

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

References

1. Ajis A, Geary N. Surgical technique, fusion rates, and planovalgus foot deformity correction with naviculocuneiform fusion. *Foot Ankle Int*. 2014;35(3):232-237.
2. Bloome DM, Marymont JV, Varner KE. Variations on the insertion of the posterior tibialis tendon: a cadaveric study. *Foot Ankle Int*. 2003;24(10):780-783.
3. Buda M, Hagemeijer N, Kink S, et al. Effect of fixation type and bone graft on tarsometatarsal fusion. *Foot Ankle Int*. 2018; 39(12):1394-1402.
4. Burchard R, Massa R, Soost C, et al. Biomechanics of common fixation devices for first tarsometatarsal joint fusion—a comparative study with synthetic bones. *J Orthop Surg Res*. 2018; 13(1):176.
5. Coetzee JC, Resig SC, Kuskowski M, Saleh KJ. The Lapidus procedure as salvage after failed surgical treatment of hallux valgus: a prospective cohort study. *J Bone Joint Surg Am*. 2003;85(1):60-65.
6. Coetzee JC, Wickum D. The Lapidus procedure: a prospective cohort outcome study. *Foot Ankle Int*. 2004;25(8):526-531.
7. Cottom JM, Baker JS. Comparison of locking plate with interfragmentary screw versus plantarly applied anatomic locking plate for Lapidus arthrodesis: a biomechanical cadaveric study. *Foot Ankle Spec*. 2017;10(3):227-231.
8. Dayton P, Hatch DJ, Santrock RD, Smith B. Biomechanical characteristics of biplane multiplanar tension-side fixation for Lapidus fusion. *J Foot Ankle Surg*. 2018;57(4):766-770.
9. DeVries J, Grenata J, Hyer C. Fixation of first tarsometatarsal arthrodesis: a retrospective comparative cohort of two techniques. *Foot Ankle Int*. 2011;32(2):158-162.

10. Drummond D, Motley T, Kosmopoulos V, Ernst J. Stability of locking plate and compression screws for Lapidus arthrodesis: a biomechanical comparison of plate position. *J Foot Ankle Surg*. 2018;57(3):466-470.
11. Gutteck N, Wohlrab D, Zeh A, Radetzki F, Delank KS, Lebek S. Comparative study of Lapidus bunionectomy using different osteosynthesis methods. *Foot Ankle Surg*. 2013;19(4):218-221.
12. Gutteck N, Savov P, Panian M, Wohlrab D, Zeh A, Delank KS. Preliminary results of a plantar plate for Lapidus arthrodesis. *Foot Ankle Surg*. 2018;24(5):383-388.
13. Gutteck N, Wohlrab D, Zeh A, Radetzki F, Delank KS, Lebek S. Immediate fullweightbearing after tarsometatarsal arthrodesis for hallux valgus correction—does it increase the complication rate? *Foot Ankle Surg*. 2015;21(3):198-201.
14. Jarusriwanna A, Chuckpaiwong B. Appropriate area for operative procedures near tibialis anterior tendon insertion: a cadaveric study. *Foot Ankle Int*. 2018;39(3):349-354.
15. Klos K, Simons P, Hajduk AS, et al. Plantar versus dorsomedial locked plating for Lapidus arthrodesis: a biomechanical comparison. *Foot Ankle Int*. 2011;32(11):1081-1085.
16. Klos K, Wilde CH, Lange A, et al. Modified Lapidus arthrodesis with plantar plate and compression screw for treatment of hallux valgus with hypermobility of the first ray: a preliminary report. *Foot Ankle Surg*. 2013;19(4):239-244.
17. Plaass C, Claassen L, Daniilidis K, et al. Placement of plantar plates for Lapidus arthrodesis: anatomical considerations. *Foot Ankle Int*. 2016;37(4):427-432.
18. Pope EJ, Takemoto RC, Kummer FJ, Mroczek KJ. Midfoot fusion: a biomechanical comparison of plantar planting vs intramedullary screws. *Foot Ankle Int*. 2013;34(3):409-413.
19. Roth KE, Peters J, Schmidtmann I, Maus U, Stephan D, Augat P. Intraosseous fixation compared to plantar plate fixation for first metatarsocuneiform arthrodesis: a cadaveric biomechanical analysis. *Foot Ankle Int*. 2014;35(11):1209-1216.
20. Sangeorzan BJ, Hansen ST. Modified Lapidus procedure for hallux valgus. *Foot Ankle*. 1989;9(6):262-266.
21. Simons P, Fröber R, Loracher C, et al. First tarsometatarsal arthrodesis: an anatomic evaluation of dorsomedial versus plantar plating. *J Foot Ankle Surg*. 2015;54(5):787-792.
22. Thompson IM, Bohay DR, Anderson JG. Fusion rate of first tarsometatarsal arthrodesis in the modified Lapidus procedure and flatfoot reconstruction. *Foot Ankle Int*. 2005;26(9):698-703.
23. Toolan BC. Surgical strategies: the Lapidus procedure. *Foot Ankle Int*. 2007;28(10):1108-1114.