U·P·O·J

Comparison of Four Different Fixation Strategies for Midfoot Arthrodesis: A Retrospective Comparative Study

Wonyong Lee, MD[1]
Dan Prat, MD[1]
Keith L. Wapner, MD[1]
Daniel C. Farber, MD[1]
Wen Chao, MD[1]

[1]Division of Foot & Ankle Surgery
Department of Orthopaedic Surgery
University of Pennsylvania

Introduction

The midfoot joints transfer load from the hindfoot to the forefoot. This transfer occurs in every step and is particularly important during the push-off phase of the gait cycle making stability of the midfoot critical for daily of activity.[10] Any pathology affecting these joints such as degenerative arthritis, inflammatory arthritis, or trauma can lead to midfoot arch collapse, planovalgus deformity, and medial instability.[21] Further, dysfunction of the midfoot is associated with chronic pain, affects mechanics and results in decreased quality of life.

Nonoperative treatment for midfoot arthritis includes shoe modification, activity modification, nonsteroidal anti-inflammatory drugs (NSAIDs), corticosteroid injections, and orthotics and bracing, such as the University of California Berkeley Lab (UCBL) brace.[15,21] Operative intervention is considered if these conservative management fail. Arthrodesis of the arthritic midfoot joints is the mainstay of operative treatments. The primary goal of arthrodesis is achieving stable osseous union with correction of deformity if present. There have been several reports delineating the risk factors for nonunion, which include smoking, diabetes mellitus, poor compliance with weightbearing instructions, and osteoporosis.[5,25] Besides these risk factors associated with patients, meticulous operative technique with proper implant selection for adequate stability is critical for the success of midfoot arthrodesis. Various implant constructs exist for midfoot arthrodesis including compression plates and screws, crossed screws, and staples. Although previous studies have tried to determine the superiority of one fixation construct over another, there is no consensus regarding the optimal implant fixation strategy for midfoot arthrodesis.[3,4,9,14,22,23]

The purpose of this study was to compare the union rate of midfoot arthrodesis and the complication rate using four different fixation implant constructs: staple fixation, compression plate fixation, compression plate with lag screw fixation, and compression screw fixation. Risk factors for nonunion were also investigated.

Methods

Institutional review board approval was obtained prior to the initiation of this study. The Current Procedural Terminology (CPT) codes 28730 and 28740 were used to identify patients who underwent single or multiple midfoot joint arthrodesis between January 2014 and May 2019 at a single academic institution. The midfoot joints included tarsometatarsal (TMT), medial naviculocuneiform (NC), middle NC, lateral NC, and intercuneiform joints. The inclusion criteria were (1) age older than 18 years, (2) arthrodesis of a single or multiple midfoot joints arthrodesis using one of the fixation constructs among the following: a staple fixation, compression plate fixation, compression plate with lag screw fixation, and compression screw fixation, and (3) followup until union or nonunion could be determined. Exclusion criteria were (1) revision surgery, (2) Charcot arthropathy, (3) lack of complete records, and (4) arthrodesis via a different fixation method than the inclusion criteria.

A retrospective chart review was performed. Characteristics that were investigated included age, sex, body mass index (BMI), smoking, comorbidities such as diabetes mellitus and rheumatoid arthritis, history of steroid injection prior to surgery, etiology of arthritis, number of joints fixed, type of fixation implant, use of bone graft, time to union, time to full weightbearing, and any complication including nonunion, wound infection, and hardware irritation.

Postoperative radiographs were used to assess the bony healing of the operative midfoot joints. Delayed union was defined as an absence of fusion by 12 weeks postoperative followup, which has been previously described.[18] Although the definition of nonunion for midfoot arthrodesis is poorly defined in the literature, lack of radiographic union by 6 months without progression on sequential radiographs was used in this study.[4,22] The first postoperative weightbearing radiographs taken between 6 weeks and 12 weeks postoperative followup were utilized to evaluate the alignment of the operatively corrected foot[17,19] The following criteria were used to assess alignment: (1) Anteroposterior (AP) Radiograph: the alignment between the medial edge of the second metatarsal and the medial edge of the middle cuneiform bone, (2) Internal Oblique Radiograph: the alignment between the medial border of the third metatarsal and the medial border of lateral cuneiform and between the medial border of the fourth metatarsal and the medial border of the cuboid bone, (3) Lateral Radiograph: the talo-first metatarsal angle (Meary's angle) was measured as the angle formed by a line originating from the center of the body of the talus, bisecting the talar neck and head, and the line through the longitudinal axis of the first metatarsal. Lateral foot alignment was considered as anatomic if the Meary's angle was between 4 degrees and -4 degrees. If any view of postoperative weightbearing radiographic parameters was not anatomic, it was considered to be nonanatomic alignment.

The primary outcomes in this study were radiographic evidence of complete union in patients who underwent midfoot joint arthrodesis and any postoperative complication including wound problem, hardware irritation, and infection. All of these outcomes were compared among four different types of fixation constructs. The secondary outcome was identifying risk factors of nonunion.

A total of 95 patients (99 feet) were included in the final analysis. The mean age of the cohort was 60.5 ± 10.0 (range, 25 to 80) years. Overall BMI was 30.0 ± 6.1 (range, 19.8 to 48.7) on the average. There were 17 (17.2%) males and 82 (82.8%) females. A total of 240 midfoot joints were treated: 25 (10.4%) joints with a staple fixation, 19 (7.9%) joints with compression plate fixation, 90 (37.5%) joints with compression plate with lag screw fixation, and 106 (44.2%) joints with compression screw fixation. Patient demographics data are shown in Table 1. The mean followup period was 78.4 ± 62.9 weeks (range, 6.0 to 269.4). The average time to complete union for the operative sites was 10.8 ± 3.8 weeks (range, 6.0 to 40.0). Patients were initially managed in a splint and then cast followed by a CAM boot. On average, patients were allowed to wean out of the boot and initiate full weight bearing at 11.4 ± 2.8 weeks (range, 6.0 to 19.57).

All procedures were performed by one of three foot and ankle fellowship trained surgeons at a single academic institution. They were completed in the supine position and under tourniquet control. The midfoot arthrodesis was performed with a single or dual incision depending on the affected joints. If arthrodesis involved 1st TMT joint or medial NC joint, a medial incision in the interval between the anterior tibialis tendon and the posterior tibialis tendon was used. If arthrodesis involved 2nd TMT joint, 3rd TMT joint, or middle/lateral NC joint, a dorsal incision was made. For all joints, sharp dissection was carried down through the joint capsule. Any osteophyte or bony spur was excised using a rongeur. Meticulous articular surfaces preparation was performed using osteotomes, curettes, and sometimes resurfacing burs. Each joint was irrigated and drilled using multiple

Table 1. Patient demographic data

Characteristic	Value
Patients, n	95
Feet, n	99
Sex, n (%)	
Male	17 (17.2)
Female	82 (82.8)
Age, years	60.5 ± 10.0 (25–80)
Body Mass Index (BMI), kg/m^2	
Overall	30.0 ± 6.1 (19.8–48.7)
≥ 30, n (%)	38 (38.4)
< 30, n (%)	61 (61.6)
Diabetes Mellitus, n (%)	13 (13.1)
Smoking, n (%)	
Current	6 (6.1)
Never	68 (68.7)
Former	25 (25.3)
Rheumatoid Arthritis, n (%)	5 (5.1)
Steroid injection prior to Surgery, n (%)	12 (12.1)
Etiology of arthritis, n (%)	
Degenerative	75 (75.8)
Posttraumatic	22 (22.2)
Inflammatory	2 (2.0)
Bone graft, n (%)	68 (68.7)
Postoperative midfoot anatomic alignment, n (%)	
Yes	88 (88.9)
No	11(11.1)
Mean followup, weeks	78.4 ± 62.9 (6.0–269.4)

passes of a drill bit. The decision to use bone graft was at the operating surgeon's discretion. However, it was used if defects or gaps were observed intraoperatively. The choice in types of bone graft was based on the surgeon's preference. Recombinant human platelet derived growth factor-BB with beta-tricalcium phosphate (rhPDGF-BB/β -TCP) (Augment; Wright medical, Memphis, Tennessee) or highly porous β -TCP (Vitoss; Stryker, Kalamazoo, Michigan) with bone marrow aspirate concentrate (BMAC) (Harvest Technologies, Plymouth, MA) were used in this study for bone graft. The joints were manipulated to achieve plantigrade alignment of the foot. Then, one of four fixation constructs were utilized with the choice of implant based on the surgeon's preference: staple fixation, compression plate fixation, compression plate with lag screw fixation, and compression screw fixation. The data associated with fixation implants are shown in Table 2. Postoperatively, a well-padded short leg splint was applied. It was converted to a short leg non-weightbearing cast at 2 weeks postoperatively. Nonweightbearing immobilization was maintained for 6 weeks from the day of surgery. The cast was removed, and a controlled ankle movement (CAM) boot was applied at 6 weeks postoperative followup visit. The patients were advised to bear weight in the CAM boot as tolerated. Radiographic evaluation of the union was performed between 6 weeks and 12 weeks postoperative followup visit. If there were any clinical symptoms such as pain or swelling, or radiological evidence of nonunion, then a further period of non-weightbearing was recommended.

All statistical analyses were performed with SPSS software (version 21.0; IBM, Armonk, NY, USA). Data are presented as the mean and standard deviation. Continuous variables such as age and overall BMI were compared using one-way analysis of variance (ANOVA), and categorical variables were compared using chi-square test or Fisher exact test. Bonferroni correction method post hoc analysis was performed after chi-square test to investigate which fixation construct had a statistical significance in terms of the nonunion rate (Table 3); a significant difference was found only in compression screw alone fixation group regarding the nonunion rate. All variables which can affect the nonunion rate was

Table 2. Data associated with four different fixation constructs

Characteristic	Staple	Compression plate	Compression plate with lag screw	Compression screw	P Value
Joints, n (%),					
Overall	25 (10.4)	19 (7.9)	90 (37.5)	106 (44.2)	-
1st TMT	3	1	36	12	
2nd TMT	9	10	26	43	
3rd TMT	8	7	22	39	
Medial NC	2	1	6	9	
Middle NC	1	0	0	0	
Lateral NC	2	0	0	0	
Intercuneiform	0	0	0	3	
Female, n (%)	21 (84.0)	15 (78.9)	78 (86.7)	86 (81.1)	0.715
Age, years, mean ± SD (range)	59.5 ± 15.3 (25–76)	59.6 ± 11.8 (28–80)	62.1 ± 9.6 (30-80)	59.8 ± 9.5 (25–78)	0.415
BMI, kg/m^2, mean ± SD (range)	27.1 ± 4.6	30.0 ± 7.0	29.3 ± 5.2	30.3 ± 6.8	
Overall	(20.5-35.3)	(21–40.9)	(19.8–48.7)	(19.8–48.7)	0.108
≥ 30, n (%)	5 (20.0)	10 (52.6)	28 (31.1)	39 (36.8)	
< 30, n (%)	20 (80.0)	9 (47.4)	62 (68.9)	67 (63.2)	0.121
Laterality, n (%)					0.967
Right	13 (52.0)	9 (47.4)	42 (46.7)	52 (49.1)	
Left	12 (48.0)	10 (52.6)	48 (53.3)	54 (50.9)	
Diabetes Mellitus, n (%)	0 (0.0)	6 (31.6)	8 (8.9)	12 (11.3)	**0.008**
Smoking, n (%)					0.218
Current	0 (0.0)	0 (0.0)	4 (4.4)	10 (9.4)	
Never	16 (64.0)	16 (84.2)	65 (72.3)	69 (65.1)	
Former	9 (36.0)	3 (15.8)	21 (23.3)	27 (25.5)	
Rheumatoid Arthritis, n (%)	0 (0.0)	0 (0.0)	4 (4.4)	10 (9.4)	0.136
Steroid injection prior to Surgery, n (%)	2 (8.0)	8 (42.1)	6 (6.7)	8 (7.5)	**< 0.001**
Etiology of arthritis, n (%)					0.404
Degenerative	16 (64.0)	17 (89.5)	68 (75.6)	80 (75.5)	
Posttraumatic	9 (36.0)	2 (10.5)	20 (22.2)	22 (20.8)	
Inflammatory	0 (0.0)	0 (0.0)	2 (2.2)	4 (3.8)	
Bone graft, n (%)	19 (76.0)	5 (26.3)	82 (91.1)	64 (60.4)	**< 0.001**
Postoperative midfoot anatomic alignment, n (%)	0 (0.0)	6 (31.6)	5 (5.6)	16 (15.1)	**0.001**

investigated and were reported with Odds Ratio (OR) with 95% Confidence Interval (CI). Only variables with $p < 0.05$ were included in a multivariable logistic regression analysis to identify independent predictors of nonunion following midfoot arthrodesis. The level of statistical significance was set as $p < 0.05$.

Results

Overall bony union was achieved in 86 out of 99 (86.9%) patients in this study, which included 218 out of 240 (90.8%) midfoot joints. Among 22 midfoot joints which developed nonunion, five cases (22.7%) developed in 1st TMT joint; eight cases (36.4%) in 2nd TMT joint; seven cases (31.8%) in 3rd TMT joint; two cases (9.1%) in medial NC joint, respectively. In terms of the type of fixation construct, 15.8% of nonunion (3/19) with compression plate fixation; 3.3% (3/90) with compression plate with lag screw fixation; 15.1% (16/106) with compression screw fixation; 0.0% (0/25) with staple fixation was shown, respectively. We found a significant difference in the nonunion rate according to the type of fixation construct ($p = 0.011$) (Table 3). Five patients with eight midfoot joints required revision surgery due to symptomatic nonunion while the remaining patients were asymptomatic, and no further procedure was required.

Besides the complication of nonunion, another 21 postoperative complications were reported: six patients developed superficial wound infection with dehiscence, two patients had deep wound infection, 11 patients had hardware irritation, and two patients developed hardware backing out or breakage without irritation. There was no significant difference in the complication rate according to the type of fixation construct ($p = 0.237$) (Table 3). All patients with superficial wound infections were managed with oral antibiotics without need for further procedures while two patients with deep wound infections underwent irrigation and debridement with hardware removal. One of the deep infection cases was managed with vacuum assisted wound closure therapy. All 11 patients who had hardware irritation symptoms underwent a hardware removal procedure.

We also investigated risk factors of nonunion following midfoot arthrodesis. They were classified into patient-related factors and surgeon-related factors. Patient-related factors included sex, age, BMI, smoking, comorbidities such as diabetes mellitus and rheumatoid arthritis, history of steroid injection prior to surgery in the affected midfoot joints, and etiology of arthritis. We stratified patients into subgroups for several variables: ≥ 65 years and < 65 years in age; ≥ 30 and < 30 in BMI. Surgeon-related factors included the type of fixation construct, the use of bone graft, and the postoperative anatomic alignment of the foot. Variables in each category were investigated with OR with 95% CI. Variables which had a significant difference with $p < 0.05$ in the nonunion rate were included in the multivariable logistic regression analysis: Diabetic Mellitus ($p = 0.001$; OR: 4.888 [95% CI: 1.775, 13.461]), history of steroid injection prior to surgery ($p = 0.037$; OR: 3.080 [95% CI: 1.023, 9.278]), bone graft ($p = 0.006$; OR: 0.032 [95% CI: 0.124, 0.737]), postoperative midfoot anatomic alignment ($p = 0.013$; OR: 0.284 [95% CI: 0.100, 0.805]), and type of fixation construct ($p = 0.009$). Post hoc analysis (Bonferroni correction method) was completed to investigate which fixation construct showed a statistically significant difference regarding the nonunion rate among four different types of fixation constructs. The compression screw alone fixation construct was noted as the only group which reached a statistical significance in the nonunion rate. Our multivariable logistic regression analysis identified diabetes mellitus, the type of fixation construct (compression screw alone), lack of adjuvant bone graft, and the postoperative nonanatomic alignment as independent predictors of nonunion following midfoot arthrodesis (Table 4).

Discussion

Our results demonstrated that overall union rate of midfoot arthrodesis was 86.9% (86/99) of patients and 90.8% (218/240) of joints, which are comparable with previous studies.[9,10,15,18] Among four different fixation constructs for midfoot arthrodesis, the compression screw alone construct showed a significantly higher nonunion rate than other fixation constructs. It was identified as one of independent risk factors of nonunion through our multivariable logistic regression analysis. In addition to the fixation construct using compression screws alone, diabetes mellitus, lack of adjuvant bone graft, and postoperative nonanatomic alignment played a role as independent predictors of nonunion following midfoot arthrodesis.

Nonunion is one of the major complications of foot and ankle arthrodesis and occurs in approximately 12% (range, 3

Table 3. The rates of nonunion and postoperative complication in each fixation construct group

Characteristic	Staple	Compression plate	Compression plate with lag screw	Compression screw	P Value
Nonunion, n (%)	0/25 (0.0)	3/19 (15.8)	3/90 (3.3)	16/106 (15.1)	0.011
Complication, n (%)					
Overall	2 (8.0)	4 (21.1)	8 (8.9)	7 (6.6)	0.237
Hardware irritation	0 (0.0)	2 (50.0)	6 (75.0)	3 (42.9)	
Hardware loosening or breakage	1 (50.0)	1 (25.0)	0 (0.0)	0 (0.0)	
Superficial wound Infection w/ dehiscence	1 (50.0)	1 (25.0)	1 (12.5)	3 (42.9)	
Deep wound infection	0 (0.0)	0 (0.0)	1 (12.5)	1 (14.2)	

Table 4. Multivariable logistic regression analysis for risk factors of nonunion following midfoot arthrodesis

Characteristic	P Value	OR* (95% CI*)
Patients related risk factors		
Diabetes Mellitus (reference: yes)	0.002	0.179 (.059, .542)
Steroid injection prior to surgery	0.718	1.314 (.298, 5.799)
Surgeon related risk factors		
Type of fixation construct (Compression screw alone) (reference: other fixation constructs)	0.026	1.789 (1.071, 2.978)
Bone graft (reference: use)	0.034	2.803 (1.081, 7.268)
Postoperative midfoot nonanatomic alignment (reference: anatomic)	0.017	3.937 (1.278, 12.126)

OR*: Odds Ratio, CI*: Confidence Interval

to 23%) of foot and ankle fusions.[7,8,11,24,27] Specifically, the rate of nonunion following midfoot arthrodesis has been reported variously from 2.0% to 12%.[9,13,15,18,22] As nonunion of midfoot arthrodesis may not result in satisfactory outcomes in the long term, every effort should be made to mitigate or avoid risk factors for nonunion.[18] A recent current concepts review of nonunion risk factors in foot and ankle arthrodesis surgery found fair evidence to support smoking, diabetes mellitus, and soft tissue injury as risk factors.[26] Variables such as higher BMI, rheumatoid arthritis, etiology of arthritis, or steroid injection prior to surgery may affect the rate of nonunion after midfoot arthrodesis. However, there is currently not sufficient evidence to support their association with nonunion. There have been just a few clinical studies reporting the predictors of nonunion.[15,18,24,25,28] Nemec et al.[18] investigated outcomes following midfoot arthrodesis for 95 cases of primary arthritis. One of their findings suggested that a higher BMI was associated with inferior clinical results leading to more complications and less improvement in AOFAS scores. In this study, we stratified patients into two subgroups based on their BMI ($\geq$ 30 vs $<$ 30) but the result did not reach statistical significance in the rate of nonunion: 12.2% (10/82) in $\geq$ 30 group vs 7.6% (12/158) in $<$ 30 group, $p = 0.241$. Patients who had a steroid injection prior to the index surgery had a significantly higher nonunion rate ($p = 0.037$, OR: 3.080, [95% CI: 1.023, 9.278]). However, it was not identified as an independent predictor of nonunion when it was included in the multivariable regression analysis.

There is currently insufficient data in the literature to show difference in outcomes following midfoot arthrodesis according to the etiology of arthritis. Several studies only reported outcomes of midfoot arthrodesis in patients of primary degenerative arthritis. Therefore, the association between the etiology of midfoot arthritis and outcomes following arthrodesis procedure were not determined.[13,18] On the other hand, Mann and his colleagues included all types of arthritis in their study and investigated clinical outcomes of mid-tarsal and TMT arthrodesis surgery. They included 17 patients of posttraumatic arthritis, 21 patients of primary degenerative arthritis, and two patients of inflammatory arthritis. During the followup period, a total of three nonunion occurred: two cases with posttraumatic arthritis and the other case with primary degenerative arthritis.[15] Similar to Mann's study, we classified the etiology of arthritis into three categories. Although our study showed a trend indicating a higher nonunion rate in posttraumatic arthritis than other etiologies, it did not reach statistical significance ($p = 0.069$).

There is a paucity of information regarding surgeon-related risk factors for nonunion in the literature. The type of fixation implant, the use of bone graft, and the postoperative midfoot alignment can be considered as surgeon or operation-related risk factors of nonunion. Many biomechanical studies have tried to determine the most stable fixation implant strategy for midfoot arthrodesis in an effort to decrease the nonunion rate. The stability of different fixation implants and different fixation configurations for midfoot arthrodesis have been compared in previous studies including compression screws, compression plates with or without screws, H-locking plates, staples, or even external fixators.[3,14,16,20,23,29] Besides biomechanical studies, several clinical studies also examined the nonunion rate according to the fixation methods for midfoot arthrodesis.[2,10,22] However, there is still little evidence in terms of the superiority of one fixation device over the others. Buda et al.[2] compared the nonunion rate among three different hardware configurations: Cross-screw fixation, isolated plate fixation, and plate with compression screw fixation. The authors reported that the use of isolated plate fixation was significantly associated with delayed wound healing as well as with nonunion in their study. Gougoulias and Lampridis[10] reported that plates provided better initial stability allowing earlier mobilization, and compression screw fixation might be problematic in osteoporotic bone. The rates of nonunion were similar between screws alone and plate with screws without a significant difference. However, total sample size was only 30 patients in their study, and the authors stated that their study was underpowered to detect differences in outcomes. Additionally, they did not advocate the use of staples as they failed to have adequate control of compression and stability. On the contrary, Schipper and his colleagues[22] advocated the use of staples for midfoot and hindfoot arthrodesis. A high union rate of 95.3% (142/149) of joints was shown in their study. They also reported no significant difference in the union rate between a staple construct and a staple with a compression screw: 95.1% (98/103) and 95.7% (44/46), respectively.

In our study, compression screw fixation alone showed a significantly higher nonunion rate than the other three fixation constructs. In addition, this study revealed that staple fixation construct had 100% union rate with a low complication rate. This finding failed to reach statistical significance due to the small sample size as our institution started using staples for midfoot arthrodesis in 2017. Despite this, staple fixation has many advantages such as shorter operation time and lower cost than anatomic locked plate and screw implant.[22] Previous biomechanical studies showed nitinol staples created a larger contact area and more contact force, and maintain time zero contact force and contact area after mechanical loading, unlike a compression plate and screw construct.[1,12] Staples can be considered as a viable alternative to the traditional fixation configuration such as plates or screws.

Various types of bone graft have been used to maximize the union rate in foot and ankle arthrodesis procedures. DiGiovanni and his colleagues[6] demonstrated the substantial value of using bone graft in hindfoot and ankle arthrodesis: Autograft or rhPDGF-BB/β -TCP was used in their study. About 80% of joints with adequate graft fill, which was defined as ≥ 50% of the cross-sectional area of the fusion site on computed tomography (CT), achieved successful fusion. No significant difference was noted based on type of graft material, graft harvest site, joint type, and number of joints fused in their study. Buda et al.[2] evaluated the effect of autologous bone grafting on TMT joint fusion and reported significant reduction in nonunion rate when they used bone graft. The result in our study also confirmed the positive effect of bone graft on the union rate in midfoot arthrodesis: Highly porous β -TCP with BMAC or rhPDGF-BB/β -TCP bone graft was used in our study. The nonunion rate was significantly reduced when bone graft was used for midfoot arthrodesis.

Plantigrade foot position and anatomic alignment following midfoot arthrodesis are essential to transfer the loading properly from hindfoot to forefoot. Mann et al.[15] demonstrated that realignment of the foot in midfoot arthrodesis can lead to a satisfactory result for posttraumatic arthritis as well as primary degenerative arthritis. Buda et al.[2] showed that nonanatomic alignment following TMT arthrodesis was a significant predictor of nonunion in their multivariable logistic regression analysis. Furthermore, several studies reported sesamoid problems after midfoot arthrodesis procedure due to nonanatomic alignment.[13,15] Sesamoid pain following midfoot arthrodesis may come from the loss of flexibility of the first ray. It also can be explained by inappropriate plantarflexion of the first ray following the surgery. Thus, anatomic realignment of the foot should be considered as a critical factor to achieve better outcomes following midfoot arthrodesis. In this study, postoperative nonanatomic alignment was identified as an independent risk factor of nonunion. Nonanatomic alignment had about 4-fold increase in nonunion. (OR: 3.937, [95% CI: 1.278, 12.126]).

There are several limitations to our study. First, there is an inherent risk of bias as it was a retrospective study. The completeness and validity of the data relied on the content of the medical record. Second, the determination of nonunion was based on plain radiograph and chart review rather than CT imaging which has been considered to be the gold standard for assessing nonunion. Third, our study did not investigate clinical functional scores. Fourth, we did not exclude patients with additional procedures at the same time of midfoot arthrodesis procedure. This may have changed the period of non-weightbearing postoperatively which could affect the outcome of nonunion. Lastly, the choice of implant fixation construct was decided by the surgeon's preference and was not randomized.

Conclusion

To the best of our knowledge, this study is the largest single-center report on midfoot arthrodesis. The rate of nonunion following midfoot arthrodesis among four different commonly used fixation constructs was compared and risk factors for nonunion were investigated revealing that diabetes mellitus, compression screw fixation alone, lack of adjuvant bone graft, and postoperative nonanatomic alignment are independent predictors of nonunion following midfoot arthrodesis. Identification of these independent predictors for nonunion provides guidance for orthopaedic surgeons to improve fusion rates in midfoot arthrodesis.

References

1. Aiyer A, Russell NA, Pelletier MH, *et al.*. The Impact of Nitinol Staples on the Compressive Forces, Contact Area, and Mechanical Properties in Comparison to a Claw Plate and Crossed Screws for the First Tarsometatarsal Arthrodesis. *Foot Ankle Spec.* 2016;9(3):232-240.

2. Buda M, Hagemeijer NC, Kink S, *et al.* Effect of Fixation Type and Bone Graft on Tarsometatarsal Fusion. *Foot Ankle Int.* 2018;39(12):1394-1402.

3. Cohen DA, Parks BG, Schon LC. Screw fixation compared to H-locking plate fixation for first metatarsocuneiform arthrodesis: a biomechanical study. *Foot Ankle Int.* 2005;26(11):984-989.

4. DeVries JG, Granata JD, Hyer CF. Fixation of first tarsometatarsal arthrodesis: a retrospective comparative cohort of two techniques. *Foot Ankle Int.* 2011;32(2):158-162.

5. DiDomenico LA and Thomas, ZM. Osteobiologics in foot and ankle surgery. *Clin Podiatr Med Surg.* 2015;32(1):1-19.

6. DiGiovanni CW, Lin SS, Daniels TR, *et al.* The Importance of Sufficient Graft Material in Achieving Foot or Ankle Fusion. *J Bone Joint Surg Am.* 2016;98(15):1260-1267.

7. Easley ME, Trnka HJ, Schon LC, *et al.*. Isolated subtalar arthrodesis. *J Bone Joint Surg Am.* 2000;82(5):613-624.

8. Ferkel RD and Hewitt M. Long-term results of arthroscopic ankle arthrodesis. *Foot Ankle Int.* 2005;26(4):275-280.

9. Filippi J, Myerson MS, Scioli MW, *et al.* Midfoot arthrodesis following multi-joint stabilization with a novel hybrid plating system. *Foot Ankle Int.* 2012;33(3):220-225.

10. Gougoulias N and Lampridis V. Midfoot arthrodesis. *Foot Ankle Surg.* 2016;22(1):17-25.

11. Gougoulias NE, Agathangelidis FG, Parsons SW. Arthroscopic ankle arthrodesis. *Foot Ankle Int.* 2007;28(6):695-706.

12. Hoon QJ, Pelletier MH, Christou C. Biomechanical evaluation of shape-memory alloy staples for internal fixation-an in vitro study. 2016;3(1):19.

13. Jung, HG Myerson MS, Schon LC. Spectrum of operative treatments and clinical outcomes for atraumatic osteoarthritis of the tarsometatarsal joints. *Foot Ankle Int.* 2007;28(4):482-489.

14. Klos K, Gueorguiev B, Muckley T, *et al.* Stability of medial locking plate and compression screw versus two crossed screws for lapidus arthrodesis. *Foot Ankle Int.* 2010;31(2):158-163.

15. Mann RA, Prieskorn D, Sobel M. Mid-tarsal and tarsometatarsal arthrodesis for primary degenerative osteoarthrosis or osteoarthrosis after trauma. *J Bone Joint Surg Am.* 1996;78(9):1376-1385.

16. Marks RM, Parks BG, Schon LC. Midfoot fusion technique for neuroarthropathic feet: biomechanical analysis and rationale. *Foot Ankle Int.* 1998;19(8):507-510.

17. Moracia-Ochagavia I, and Rodriguez-Merchan EC. Lisfranc fracture-dislocations: current management. *EFORT Open Rev.* 2019;4(7):430-444.

18. Nemec SA, Habbu RA, Anderson JG, *et al*. Outcomes following midfoot arthrodesis for primary arthritis. *Foot Ankle Int*. 2011;32(4):355-361.

19. Podolnick JD, Donovan DS, DeBellis N, *et al.* Is Pes Cavus Alignment Associated With Lisfranc Injuries of the Foot? *Clin Orthop Relat Res*. 2017;475(5):1463-1469.

20. Roth, KE, Peters, J, Schmidtmann, I, *et al.* Intraosseous fixation compared to plantar plate fixation for first metatarsocuneiform arthrodesis: a cadaveric biomechanical analysis. *Foot Ankle Int*. 2014;35(11):1209-1216.

21. Sayeed SA, Khan FA, Turner NS, *et al.* Midfoot arthritis. *Am J Orthop (Belle Mead NJ)*. 2008;37(5):251-256.

22. Schipper ON, Ford SE, Moody PW, *et al.* Radiographic Results of Nitinol Compression Staples for Hindfoot and Midfoot Arthrodeses. *Foot Ankle Int*. 2018;39(2):172-179.

23. Scranton PE, Coetzee JC, Carreira D. Arthrodesis of the first metatarsocuneiform joint: a comparative study of fixation methods. *Foot Ankle Int*. 2009;30(4):341-345.

24. Thevendran G, Shah K, Pinney SJ, *et al.* Perceived risk factors for nonunion following foot and ankle arthrodesis. *J Orthop Surg (Hong Kong)*. 2017;25(1):2309499017692703.

25. Thevendran G, Wang C, Pinney SJ, *et al.* Nonunion Risk Assessment in Foot and Ankle Surgery: Proposing a Predictive Risk Assessment Model. *Foot Ankle Int*. 2015;36(8):901-907.

26. Thevendran G, Younger A, Pinney S. Current concepts review: risk factors for nonunions in foot and ankle arthrodeses. *Foot Ankle Int*. 2012;33(11):1031-1040.

27. Thordarson DB and Kuehn S. Use of demineralized bone matrix in ankle/hindfoot fusion. *Foot Ankle Int*. 2003;24(7):557-560.

28. Verhoeven N, and Vandeputte G. Midfoot arthritis: diagnosis and treatment. *Foot Ankle Surg*. 2012;18(4):255-262.

29. Webb B, Nute M, Wilson S, *et al.* Arthrodesis of the first metatarsocuneiform joint: a comparative cadaveric study of external and internal fixation. *J Foot Ankle Surg*. 2009;48(1):15-21.