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Factors Associated With Nonunion in Arthrodesis of the First Metatarsophalangeal Joint: A Multicenter Retrospective Cohort Study

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Abstract

Background: Arthrodesis of the first metatarsophalangeal joint is the current treatment of choice for symptomatic advanced hallux rigidus and moderate-to-severe hallux valgus. There are different methods to perform arthrodesis, yet no consensus on the best approach. Therefore, this study aimed to determine the effects of preoperative and postoperative hallux valgus angle (HVA), joint preparation and fixation technique, and postoperative immobilization on the incidence of nonunion.

Methods: A retrospective multicenter cohort study was performed that included 794 patients. Univariate and multiple logistic regression was conducted to determine associations between joint preparation, fixation techniques, postoperative immobilization, weightbearing, and pre- and postoperative HVA with nonunion.

Results: Nonunion incidence was 15.2%, with 11.1% symptomatic and revised. Joint preparation using hand instruments (OR 3.75, CI 1.90-7.42) and convex/concave reamers (OR 2.80, CI 1.52-5.16) were associated with greater odds of a nonunion compared to planar cuts. Joint fixation with crossed screws was associated with greater odds of nonunion (OR 2.00, CI 1.11-3.42), as was greater preoperative HVA (OR 1.02, CI 1.00-1.03). However, the latter effect disappeared after inclusion of postoperative HVA in the model, with a small association identified between residual postoperative HVA and nonunion (OR 1.04, CI 1.01-1.08). Similarly, we found an association between odds of nonunion and higher body weight (OR 1.02, CI 1.01-1.04) but not of body mass index.

Conclusion: Based on our results, first metatarsophalangeal joint arthrodesis with planar cuts and fixation with a plate and interfragmentary screw is associated with the lowest odds of resulting in a nonunion. Higher body weight and greater preoperative HVA were associated with slight increase in rates of nonunion. It is crucial to properly correct the hallux valgus deformity during surgery.

Level of Evidence: Level III, retrospective case control study.

Keywords: arthrodesis, fusion, first metatarsophalangeal joint, hallux valgus, hallux rigidus

Introduction

Arthrodesis of the first metatarsophalangeal joint (MTPJ) is the treatment of choice for symptomatic hallux rigidus and moderate-to-severe hallux valgus. Such surgery can be used as salvage procedure for failed hallux valgus correction osteotomies.[14,16,34] Different operative techniques and fixation methods have been described, but there is no consensus on the optimal interventional approach.[20,21,26] The articular surface can be prepared using hand instruments or power tools such as an oscillating saw or convex-concave reamers.[16,21] Planar cuts are surgically the most challenging procedure, the main drawbacks being the difficulty of correcting for hallux malalignment and shortening.[13,16] When using reamers, alignment correction is more straightforward; however, several biomechanical studies suggest it is inferior to planar cuts.[4,25,29] The rationale for using hand instruments is the absence of thermal damage related to using

power tools.[2,3,22,30,] In a systematic review by Korim et al,[20] manual cartilage removal was the least associated with nonunion.

Concerning fixation methods, a plate combined with an interfragmentary screw is biomechanically the most stable, but crossed screws are only slightly weaker.[6,15,25] This is why, considering the significant cost difference, crossed-screw fixation tends to be the preferred technique.[18]

Various studies describe a range of postoperative weight-bearing. However, a systematic review by Crowell et al[9] does not draw firm conclusions as to whether there is a difference between immobilization with a surgical shoe or a lower leg cast.

Several studies suggest that in addition to the technical factors of surgery and immobilization, the indication is also crucial in relation to nonunion.[6,11,19] Patients with moderate to severe hallux valgus are at greater risk of nonunion, yet Weigelt et al[33] consider residual hallux valgus deformity as the most critical risk factor.

With an incidence of 0% to 24%, nonunion is a common complication, often leading to breakage of the internal fixation—but even so, nonunion can be well tolerated.[5,12,16,20,26] In symptomatic nonunion, the most common management is to revise the arthrodesis. Hardware removal combined with debridement is another reasonable option.[5,17]

There are various publications on risk factors for nonunion after first MTPJ arthrodesis,[8,32,33] albeit with much heterogeneity in terms of patient population and treatment.[20,26] Hence this study aimed to determine the potential association of patient factors, joint preparation, joint fixation, joint positioning, and postoperative immobilization on the incidence of nonunion.

Materials and Methods

A retrospective multicenter cohort study was conducted. All patients who underwent primary first MTPJ arthrodesis in one of 4 participating teaching hospitals in the Netherlands (Isala Zwolle, Martini Hospital Groningen, Medisch Spectrum Twente Enschede, and Rijnstate Hospital Arnhem) between January 2012 and December 2019 were included. Regarding surgical technique, standard preoperative antibiotic prophylaxis was given (2 g of cefazolin). A medial approach was generally used. As the operations took place in teaching hospitals, the operations were performed by qualified orthopaedic surgeons or supervised residents. All data came from medical records. Patients without preoperative data (n = 2), with unclear surgical technique (n = 13), or with missing follow-up data (n = 1) were excluded. Patients with infrequent fixation methods were also excluded from the analysis: single screw (n = 8), parallel screws (n = 3), staples (n = 8), and K-wires (n = 1).

Measures

Dependent variable. Primary outcome was the incidence of first MTPJ nonunion. Nonunion was defined as the absence of radiologic signs of bony bridging and/or hardware failure (radiolucency/osteolysis, hardware failure, or migration) after at least 6 months' follow-up.[8] The distinction between symptomatic or asymptomatic was made by the presence of pain and/or loss of function with radiologic evidence of nonunion.

Independent variables. The following independent variables were included: articular surface preparation methods (planar cuts, convex/concave reamers, or manual preparation with hand instruments), fixation methods (a plate combined with an interfragmentary screw, crossed screws, or only a plate), type of postoperative immobilization (6 weeks of hallux cast/foot cast combined with forefoot off-load shoes, 6 weeks of short leg cast combined with forefoot off-load shoes, and 8-12 weeks of hallux cast/foot cast combined with forefoot off-load shoes), and preoperative and postoperative hallux valgus angle (HVA), measured on the last radiograph before and the first radiograph after surgery.

Covariates. Anthropometric data (sex, age, body height and weight, BMI), operated side (right/left), American Society of Anesthesiologists (ASA) classification (categorized as ≤II and ≥III), smoking habits (yes/no), additional surgical procedures on the forefoot (yes/no), type of revision surgery, and wound infection or wound healing disorders (yes/no) were registered. The latter was defined as wound dehiscence or signs of inflammation 2 weeks after surgery.[28]

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Statistical analysis. All data was processed in SPSS (version 28.0, IBM Inc, Armonk, NY) for statistical analysis. Descriptive statistics were used to describe sample characteristics. Normally distributed data are presented as mean with standard deviation, and non-normally distributed data as median with interquartile range. Categorical data are presented as a number with corresponding percentage.

Univariate logistic regression analysis was performed to identify differences between first MTPJ union vs nonunion, with union as reference category. Subsequently, all factors with $P < .157$ were entered into a multiple regression analysis.[8,32] A forward regression procedure was used to evaluate the significance and fit statistics (–2 log-likelihood). As a secondary analysis, postoperative HVA was included in the model. Body height and weight, as well as BMI, were all entered into the univariate analysis. However, as BMI is considered a composed variable of body height and weight, it was not included in the multiple regression analysis. Smoking was not included in the univariate or multiple regression analysis because of limited registration in the patient files. The results were reported as odds ratios (ORs) with 95% CIs. Continuous variables were also presented with the nonstandardized regression coefficient (log odds). Differences were considered statistically significant with a P value $< .05$.

Ethics, data sharing, funding, and potential conflicts of interest. The local ethics committee of Martini Hospital approved the study before initiation (registration no. 2020-003, issued January 23, 2020). The data sets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. No funding was obtained, and the authors have no conflicts of interest to declare.

Results

Our sample included 794 first MTPJ arthrodesis performed; 216 (27.2%) patients were male, 578 (72.8%) female. Mean age of patients was 61.2 years (SD 10.8). These and other characteristics can be found in Table 1.

Overall Nonunion Frequency and Revision

Our cohort's overall nonunion frequency was 121 (15.2%); 88 (11.1%) patients had symptomatic nonunion and were surgically revised. Median follow-up of patients with symptomatic nonunion was 379.8 days (range 1-2591). Reasons for secondary surgery within 6 months of follow-up were complaints of hardware migration (n = 4) and malposition (n = 1). Excluding nonunion, 72 of 673 patients (10.7%) underwent secondary surgery. Details of the secondary surgeries can be found in Table 2.

Joint preparation methods. Three types of joint preparation methods were used: hand instruments, such as curettes and rongeurs (n = 133; 16.8%); convex/concave reamer (n = 425; 53.5%); and planar cuts (n = 236; 29.7%) (Table 1). Nonunion frequency was 24.1% for hand instruments, 16.2% for convex/concave reamers, and 8.5% for planar cuts. Multiple logistic regression revealed that the use of hand instruments (OR = 3.75, CI 1.90-7.42) and of a convex/concave reamer (OR = 2.80, CI 1.52-5.16) had a statistically significant association with nonunion compared to planar cuts (Table 3).

Joint fixation methods. Three methods were used to fixate the arthrodesis: crossed screws (n = 561; 70.1%), plate combined with interfragmentary screw (n = 200; 25.2%), and plate alone (n = 33; 4.2%). Of the plates used, 98% were dedicated hallux fusion plates (from various manufacturers), and the remaining 2% were semitubular plates. Nonunion frequency was 16.4% for crossed screws, 11.0% for a plate combined with an interfragmentary screw, and 21.2% for plate only. Multiple logistic regression revealed that the use of crossed screws (OR 2.00, CI 1.11-3.42) had a statistically significant association with nonunion compared to a plate combined with an interfragmentary screw (Table 3).

Postoperative weightbearing and immobilization. Postoperative weightbearing was divided into 3 categories: 6 weeks of hallux cast/foot cast combined with forefoot off-load shoes (n = 661; 83.2%), 6 weeks of short leg cast combined with forefoot off-load shoes (n = 119; 15.0%), and 8-12 weeks of hallux cast/foot cast combined with forefoot off-load shoes (n = 14; 1.8%). No statistically significant differences with first MTPJ nonunion were found between these options during multiple logistic regression analysis (Table 3).

Hallux valgus angle. Mean HVA in the nonunion group was 30.0 degrees (SD 14.4 degrees) compared to 26.8 degrees (SD 14.4 degrees) in the union group (Table 1). The multiple logistic regression revealed a significant association between greater preoperative HVA and nonunion in model 1 (OR 1.02, 95% CI 1.00-1.03) (Table 3). After the inclusion of postoperative HVA in model 2 (Table 3), preoperative HVA no longer remained significant. However, a significant association was now seen between residual postoperative HVA and nonunion (OR 1.04, 95% CI 1.01-1.08) (Table 3).

Body weight. As body height and weight had a $P < .157$, these were entered into the multiple analyses instead of BMI. BMI is considered a composed variable of body height and weight, confirmed with multicollinearity between BMI and body weight (variance inflation factor [VIF] > 5.0).[31] Average body weight in the nonunion group was 84.3 (SD 17.0) compared with 77.8 (SD 15.1) in the union group. Using multivariate regression analysis, we found a significant difference (OR 1.02, 95% CI 1.01-1.04) (Table 3).

Table 1. Sample Characteristics Stratified for First MTPJ Union and Nonunion.[a]

Variable	Total (n=794)	Union (n=673)	Nonunion (n=121)
Age, y, mean (SD)	61.2 (10.8)	61.3 (11.0)	60.8 (9.7)
Sex			
Female	578	500 (86.5)	78 (13.5)
Male	216	173 (80.1)	43 (19.9)
ASA			
≤II	652	548 (84.0)	104(16.0)
≥III	69	56 (81.2)	13 (18.8)
Missing	73		
Side			
Right	418	363 (86.8)	55 (13.2)
Left	376	310 (82.4)	66 (17.6)
BMI, mean (SD)	27.5 (4.6)	27.2 (4.4)	28.6 (5.0)
Missing	69		
Body weight, kg, mean (SD)	78.8 (15.6)	77.8 (15.1)	84.3 (17.0)
Missing	69		
Body height, cm, mean (SD)	169.2 (9.4)	168.8 (9.1)	171.6 (9.1)
Missing	68		
Active smoker			
Yes	71	59 (83.1)	12 (16.9)
No	310	256 (82.6)	54 (17.4)
Missing	413		
Wound infection			
Yes	52	39 (75.0)	12 (25.0)
No	740	632 (85.4)	108 (14.6)
Missing	2		
Additional surgery on the forefoot			
Yes	583	182 (86.3)	29 (13.7)
No	211	491 (84.2)	92 (15.8)
Hallux valgus angle, degrees, mean (SD)			
Preoperative	27.3 (14.4)	26.8 (14.4)	30.0 (14.4)
Postoperative	16.2 (8.0)	15.8 (7.8)	18.2 (8.6)
Joint preparation technique			
Planar cuts	236	216 (91.5)	20 (8.5)
CC reaming	425	356 (83.8)	69 (16.2)
Manual preparation	133	101 (75.9)	32 (24.1)
Joint fixation technique			
Plate + IFS	200	178 (89.0)	22 (11.0)
Crossed screws	561	469 (83.6)	92 (16.4)
Plate only	33	26 (78.8)	7 (21.2)
Postoperative immobilization			
6-wk hallux cast	661	555 (84.0)	106 (16.0)
6-wk short leg cast	119	107 (89.9)	12 (10.1)
8-12-wk hallux cast	14	11 (78.6)	3 (21.4)

Abbreviations: ASA, American Society of Anesthesiologists classification; BMI, body mass index; CC, convex/concave; IFS, interfragmentary screw; MTPJ, metatarsophalangeal joint.
[a]Variables are presented as n or n (%) unless otherwise noted.

Discussion

First MTPJ arthrodesis is a commonly performed operation for symptomatic hallux rigidus and moderate-to-severe hallux valgus. In this study we included 794 first MTPJ arthrodeses. The incidence of nonunion was 15.2%, which is higher than presented in most current literature (5.4%-6.5%).[20,26]

In our study, 11.1% of all patients had a painful nonunion, which is higher than the 1.8% described by Roukis[26]; therefore, the revision rate found in our cohort was high. Remarkably, 26% of patients who underwent revision

Table 2. Description of Secondary Surgery.

Surgery	Symptomatic Nonunion, n (%) (n=88)	Union, n (%) (n=72)	Total Secondary Surgical Procedures, n (n=160)
Revision arthrodesis	76 (86.4)	0 (0.0)	88
Hardware removal	12 (13.6)	66 (91.7)	72
Correction osteotomy	0 (0.0)	6 (8.3)	6

surgery due to nonunion were operated after 1 year. This late-onset pain could explain our higher incidence of symptomatic nonunion when compared to studies with a shorter follow-up.

Use of hand instruments and a convex/concave reamer had a statistically significant association with nonunion compared to planar cuts. Several biomechanical studies found that planar cuts are biomechanically superior to convex/concave joint configuration.[4,25,29] Only Curtis et al found a more stable situation after using convex/concave reamers, whereas Harris et al found no difference between the 2 joint configurations.[10,15] Our current findings contradict the results of the systematic review by Korim et al,[20] who found significantly better results using hand instruments. Planar cuts have lost popularity to hand instruments and convex/concave reamers because they are more technically demanding and can sometimes lead to substantial shortening of the hallux.[13,16] However, in a cadaver study by Singh et al,[27] no significantly greater shortening with planar cuts compared with convex/concave reamers were found.

As for joint fixation, nonunion frequencies for crossed screws and plates-only are remarkably higher. However, using multivariate regression analysis, we only found a significant difference for crossed screws compared to a plate combined with an interfragmentary screw. Biomechanical and cohort studies suggest that both a dorsal plate with an interfragmentary screw and crossed screws are less associated with nonunion than a plate alone.[6,15,23] A plate combined with an interfragmentary screw is slightly more stable than crossed screws in biomechanical studies.[6,15,25] An argument for using crossed screws is the considerable cost difference.[18] Based on our findings, we advise not to use crossed screws in patients with other risk factors for nonunion.

We also evaluated postoperative weightbearing, finding no significant differences between 6 weeks of hallux cast/foot cast combined with forefoot off-load shoes, 6 weeks of short leg cast combined with forefoot off-load shoes, and 8-12 weeks of hallux cast/foot cast combined with forefoot off-load shoe. These findings are consistent with the current literature.[1,20]

Nonunion frequencies were higher in patients with a larger preoperative HVA in our first multivariate modelings. We hypothesize that preexisting intrinsic instability and persistent imbalance between the adductor hallucis and abductor hallucis in case of moderate to severe hallux valgus may require more fixation stability.[24] However, the strength of that association is small, and with inclusion of postoperative HVA in the model, we found postoperative HVA to be a stronger predictor for nonunion than preoperative HVA, in line with the findings of Weigelt et al.[33] They argue that it is crucial to properly correct the hallux valgus deformity during surgery to avoid subsequent nonunion. However, given the high correlation between preoperative and postoperative HVA ($r=0.598$, $P<.001$), preoperative HVA still appears valuable in preoperative risk assessment.

Last, higher body weight was associated with a small increase in the odds of nonunion. A higher body weight leads to a higher peak load on the foot and hallux, increasing forefoot deformation.[7] However, as there was no significant difference between diverse weightbearing and immobilization protocols, we should be careful to conclude that the load is excessive and leads to nonunion.

Strengths and Limitations

The main strength of this study is the large sample size. To our knowledge, this is the most extensive retrospective study of first MTPJ arthrodesis available, which also provides analyses of different aspects of treatment. In terms of heterogenicity, the most-used surgical techniques are well represented in our cohort. Because of the multicenter design, surgery was performed by several orthopaedic surgeons, thus increasing the results' generalizability. A limitation of the study is its retrospective design. We did not include comorbidity and lifestyle factors in our analysis, as this was not structurally registered in the patient files. We could only obtain data for smoking in 48.1% of the cases because of limited registration, yet in a sensitivity analysis only including these cases, smoking was of no influence on nonunion (OR 0.96, 95% CI 0.49-1.91).

Conclusion

In our retrospective cohort study we found an incidence of nonunion in first MTPJ arthrodesis of 15.2%. Joint preparation with hand instruments and, to a lesser extent, use of convex/concave reamers, were associated with higher odds of nonunion compared to planar cuts. Joint fixation with crossed screws was associated with higher odds of nonunion compared to a plate combined with an interfragmentary

Table 3. Univariate and Multivariate Logistic Regression Analysis Estimating the Effect of Risk Factors for Nonunion.[a]

	Univariate				Multivariate Model 1				Multivariate Model 2			
Variable	*B*	OR	*P* Value	95% CI	*B*	OR	*P* Value	95% CI	*B*	OR	*P* Value	95% CI
Age, y	−0.004	1.00	.664	0.98-1.01								
Sex (%) (ref = female)		1.59	**.026***	1.06-2.40		1.14	.679	0.61-2.12		1.12	.728	0.60-2.08
ASA (%) (ref = ≤II)		1.22	.536	0.65-2.32								
Side (%) (ref = right)		1.41	.086*	0.95-2.07		1.31	.210	0.86-2.00		1.30	.233	0.85-1.98
BMI	0.060	1.06	**.005***	1.02-1.11								
Body weight, kg	0.025	1.03	**<.001***	1.01-1.04	0.022	1.02	**.006**	1.01-1.04	0.020	1.02	**.011**	1.01-1.04
Height, cm	0.031	1.03	**.004***	1.01-1.05	0.010	1.01	.546	0.98-1.04	0.011	1.01	.520	0.98-1.04
Wound infection (ref = No)		1.95	**.047***	1.01-3.77		2.00	.065	0.96-4.17		1.99	.067	0.95-4.16
Additional surgery on the forefoot (ref = No)		0.85	.481	0.54-1.34								
Hallux valgus angle												
Preoperative	0.015	1.02	**.027***	1.00-1.03	0.018	1.02	**.019**	1.00-1.03	0.004	1.00	.706	0.99-1.02
Postoperative	0.038	1.04	**.002***	1.01-1.06					0.040	1.04	**.019**	1.01-1.08
Joint preparation (ref = planar cuts)												
CC reaming		3.42	**.006***	1.87-6.28		2.80	**<.001**	1.52-5.16		2.70	**.002**	1.46-5.00
Manual preparation		2.09	**<.001***	1.24-3.54		3.75	**<.001**	1.90-7.42		3.50	**<.001**	1.75-6.99
Joint fixation (ref = plate + IFS)												
Crossed screws		1.59	.068*	0.97-2.61		2.00	**.022**	1.11-3.62		2.06	**.017**	1.14-3.75
Plate only		2.18	.106*	0.85-5.60		2.19	.147	0.76-6.33		2.31	.131	0.78-6.81
Postoperative immobilization (ref = 6-wk hallux cast)												
6-wk short leg cast		0.59	.099*	0.31-1.11		0.83	.636	0.38-1.80		0.90	.791	0.42-1.95
8-12-wk hallux cast		1.43	.589	0.39-5.21		2.07	.306	0.51-8.32		2.19	.275	0.54-8.93

Abbreviations: ASA, American Society of Anesthesiologists classification; *B*, nonstandardized regression coefficient; BMI, body mass index; CC, convex/concave; IFS, interfragmentary screw; OR, odds ratio.

[a]Differences were considered statistically significant with a *P* value >.05 and are marked in bold.

*$P < .157$ and entered into the multiple regression analysis.

screw. Greater HVA and larger body weight were also associated with higher odds of nonunion. After including postoperative HVA in the multivariate model, we found it was a stronger predictor for nonunion than preoperative HVA—albeit with a small overall effect.

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Ethical Approval

Martini Hospital approved the study before initiation (registration no. 2020-003, issued 23 January 2020).

Declaration of Conflicting Interests

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