**Risk Factors for Non-union After First Metatarsophalangeal Joint Arthrodesis with a Dorsal Locking Plate and Compression Screw Construct: Correction of Hallux Valgus is Key**

**ABSTRACT**

**Background**

First metatarsophalangeal joint (MTPJ) arthrodesis is currently the gold standard technique for advanced hallux rigidus. It is also used for other pathologies such as severe hallux valgus deformity or failed hallux valgus correction. This retrospective study aimed to identify the risk factors for non-union after first MTPJ arthrodesis with a dorsal locking plate and compression screw construct.

**Methods**

Between April 2014 and April 2019, 165 consecutive patients (28 men and 137 women; mean age, 60 (range, 28−84) years) who underwent 178 primary first MTPJ arthrodeses were retrospectively reviewed. All arthrodeses were performed using either a dorsal locking plate with an integrated compression screw (Anchorage CP plate, Stryker, n= 97) or a dorsal locking plate (Anchorage V2 plate, Stryker, n=81) with a separate compression screw (4mm cannulated ACE screw). Union was defined as bone bridging across the fusion site on at least 2 of the 3 standard foot radiographs (anteroposterior, lateral, oblique) and no MTPJ movement or pain during clinical examination. Potential risk factors for non-union were analyzed with the use of univariate and multivariate analyses.

**Results**

The overall non-union rate was 6.2% (11 of 178 cases). ﻿The risk factors identified in the univariate analysis included preoperative hallux valgus deformity, postoperative residual hallux valgus deformity, and diabetes (P< .05). Multivariate analysis confirmed that postoperative residual hallux valgus deformity (odds ratio 6.5; P = .015) and diabetes (odds ratio 7.4; P= .019) are independent risk factors for non-union after first MTPJ arthrodesis.

**Conclusion**

Diabetes is the most important independent risk factor for non-union after first MTPJ arthrodesis with a dorsal locking plate and compression screw construct. A residual postoperative hallux valgus deformity is associated with a significantly increased risk for non-union. It is therefore crucial to correct the hallux valgus deformity to a hallux valgus angle of less than 20°.

**LEVEL OF EVIDENCE**

Level IV

**KEYWORDS**

First metatarsophalangeal joint fusion; Non-union; Arthrodesis; Dorsal locking plate

**INTRODUCTION**

In 1852, first metatarsophalangeal joint (MTPJ) arthrodesis was introduced by Broca for the treatment of hallux valgus.4 Since then, numerous operative techniques have been described including different approaches, joint preparations and fixation methods, all striving to improve the alignment of the hallux and increase the union rate. First MTPJ arthrodesis has become a well-established treatment for advanced hallux rigidus, showing high satisfaction rates, predictable pain relief, and good functional results.8,17,20 Moreover, it is widely used for other pathologies, such as severe hallux valgus deformity, failed hallux valgus surgery, and rheumatoid arthritis.11,12,21

A meta-analysis revealed an overall non-union rate of 6.5% after first MTPJ arthrodesis.29 The analysis included several aetiologies, joint preparation techniques, and arthrodesis procedures. The highest union rates were achieved in cases of hallux rigidus as the underlying pathology and when manual preparation of the joint surfaces was performed. None of the fixation techniques showed any superiority in preventing non-unions.

Several other potential risk factors have been suggested to increase the risk for first MTPJ non-union, such as previous hallux valgus surgery, male gender, rheumatoid arthritis, and diabetes.1,19,23,35 Furthermore, a preoperative hallux valgus deformity was proposed to be an independent risk factor for non-union using cross screws.28 So far, no study has reported on the non-union rate in a larger cohort of patients treated with first MTPJ arthrodesis with a locking plate and compression screw construct.

The aim of this retrospective study was to investigate potential demographic and deformity-related risk factors contributing to non-union in first MTPJ arthrodesis using a dorsal locking plate and compression screw construct, our nul hypothesis being that there were no independent risk factors to non union.

**METHODS**

**Patient selection and characteristics**

We retrospectively searched our electronic database for all consecutive first MTPJ arthrodeses performed at our institution between April 2014 and April 2019. All patients who needed first MTP arthrodesis as a revision procedure after failed fusion were excluded. We included 165 patients (28 men, 137 women) with a mean age of 60 (range, 28-84) years and a mean body mass index (BMI) of 28 (range, 19-43) kg/m2 who had undergone 178 first MTPJ arthrodeses (in the following referred to as cases). All cases had a painful, grind test positive first MTPJ, of which 8 cases were due to failed hallux valgus surgery, 29 cases had a history of rheumatoid arthritis, and 141 cases showed advanced first MTPJ arthritis or severe arthritic hallux valgus deformity. In all patients who needed bilateral first MTPJ arthrodesis, the surgery was performed as a one-step procedure. Demographical data (age, gender, BMI), comorbidities (diabetes mellitus, rheumatoid arthritis, hypothyroidism), technical aspects of the surgery (bilateral one-step surgery, implant type, joint preparation technique, previous hallux valgus surgery), and lifestyle factors (active smoking, alcohol abuse, steroid intake) were recorded (Table 1).

All surgeries had been performed or directly supervised by one of 3 fellowship-trained consultant foot surgeons (A.M., L.M., C.B.) (blinded for reviewing purpose). The joint surfaces were prepared with either cup and cone reamers (n=118) or hand tools such as bone nibblers and curettes (n=60). In 97 cases, the arthrodesis had been performed using a dorsal locking plate with an integrated dorsal to plantar compression screw (Anchorage CP MTP plating system, Stryker, Warsaw, Indiana). In 81 cases, the first MTPJ had been fused with a dorsal locking plate (Anchorage 2 MTP plating system, Stryker, Warsaw, Indiana) and a separate cannulated trans-articular compression screw (4.0 mm ACE screw, Zimmer Biomet, Warsaw, Indiana), which was inserted from plantar-medial to dorsal-lateral.

**Data collection and analysis**

﻿Preoperative and postoperative weightbearing foot radiographs ﻿were assessed using the departmental digital imaging software (﻿Vue PACS, Carestream, Version 11.4.1.0324). Union was defined as bridging bone across the fusion site on at least 2 out of the 3 standardly performed radiographs (anteroposterior (AP), oblique, and lateral), with no movement or pain present at the MTPJ on clinical examination. Any concerns of non-union were further investigated with computed tomography.

﻿Preoperative hallux valgus deformity and postoperative residual deformity were quantified by measuring the hallux valgus angle (HVA) and the intermetatarsal angle (IMA) on the AP radiographs according ﻿to the recommendations of the American Orthopaedic Foot and Ankle Society (AOFAS).13 The postoperative sagittal alignment of the fused MTPJ was quantified by measuring the dorsiflexion angle (DFA) on the lateral radiographs as described by Coughlin.12 Two independent investigators evaluated the preoperative and postoperative radiographs. ﻿Differences between the investigators of greater than 5 degrees were re-measured and resolved by consensus. ﻿

**Operative technique**

﻿All patients were positioned supine and received general anesthesia combined with an ankle block. A thigh tourniquet was used for all cases. A dorsal longitudinal incision was centered over the first MTPJ and deepened medial to the extensor hallux longus tendon through the extensor hood and the joint capsule. Care was taken to leave the insertion of the adductor tendon intact to facilitate later positioning of the hallux. After preparation of the joint surfaces with either cup and cone reamers or manual instruments, the subchondral sclerosis was penetrated with a 1.6 mm Kirschner wire (K-wire). The hallux was brought into a corrected position by pushing the proximal first metatarsal in a medial direction and thus reducing the IMA. The hallux was temporarily stabilized with a trans-articular 1.6 mm K-wire in the corrected position. The position of the hallux was then checked under image intensifier. Load bearing was simulated with a tray, included in the operation set, to ensure the correct sagittal alignment of the first MTPJ.

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For the Anchorage CP plate, a specific CP template was temporarily fixed with a 1.2 mm K-wire. After correct positioning of the template and thus the K-wire, the template was removed, and the CP reamer was inserted over the K-wire to ream the indentation for the plate. The K-wire was removed, and the Anchorage CP plate was positioned and fixed proximally with 3.0 mm locking screws. Next, the CP hole was drilled for a 3.5 mm fully threaded non-locking screw, which was inserted from dorsal proximal to plantar distal after removal of the trans-articular K-wire to ensure maximal manual compression. Finally, the distal locking screws were inserted.

If the V2 Anchorage plate was used, a 4.0 mm partially threaded cannulated screw was inserted over the K-wire, which had been previously used for temporary fixation. Special attention had been taken that the K-wire was advanced from distal-plantar-medial to proximal-dorsal-lateral through the joint surface. The screw was inserted under manual compression. The V2 Anchorage plate was positioned and temporarily fixed with 1.0 mm K-wires. After drilling and inserting the distal 3.0 mm locking screws, the long hole was drilled eccentrically to gain additional compression by inserting a non-locking 3.0mm screw. Finally, the proximal 3.0 mm locking screws were placed.

Several clinical and radiological position checks were performed throughout the procedures. After closure of the wound with interrupted subcutaneous 2-0 absorbable sutures and a running 3-0 non-absorbable suture, a sterile compressive dressing was applied.

All patients underwent the same postoperative regime with weightbearing as tolerated in a standard postoperative sandal with a stiff sole. Sutures were removed at 2 weeks postoperatively. Routine follow-up appointments, including clinical examination and standard weightbearing foot radiographs, were carried out 6 weeks postoperatively. When radiographic progression towards union was evident, ﻿patients were advanced to accommodative shoe-wear.

**Statistical Analysis**

Continuous variables are presented as mean ± standard deviation (or median and interquartile range), whereas categorical and qualitative variables are expressed as numbers and percentages. The Student t-test was used for continuous variables if the criteria for normality and equality of variances were fulfilled. Alternatively, the Mann-Whitney U test was performed. Categorical variables were analyzed using the Chi-square test for sample sets greater than 5, otherwise the Fisher’s exact test was used. A multivariate logistic regression analysis was performed including all variables with p-values of < 0.15 from the univariate analysis. The results were reported as odds ratios (OR) with 95% confidence intervals (95% CI). In general, a two-sided P < .05 was considered to be statistically significant. All data were assessed using SPSS Version 25.0 (SPSS Inc., IBM, Chicago, IL).

**RESULTS**

﻿The overall non-union rate was 6.2% (11 of 178 cases). In 3 of the 11 non-union cases, an implant failure of the arthrodesis plate was noted after a mean postoperative period of 3 (range, 1-5) months. In all 3 cases, a dorsal locking plate with an integrated trans-articular compression screw had been used (Figure 1).

The mean preoperative HVA decreased significantly from 29.5 (range, 19-43) degrees to 13.1 (range, -5-33) degrees (P< 0.001), and the mean preoperative IMA decreased significantly from 13.3 (range, 3-26) degrees to 10.5 (range, 0-20) degrees (P< 0.001). The postoperative DFA averaged 25.3 (9-44) degrees.

Factors associated with a significantly increased non-union risk in the univariate analyses were preoperative hallux valgus deformity, postoperative residual deformity, and diabetes (Table 1). Technical aspects of the surgery (bilateral surgery, implant type, joint preparation technique, previous hallux valgus surgery), lifestyle factors (smoking, alcohol abuse, steroid intake), other comorbidities (rheumatoid arthritis, hypothyroidism), and the sagittal alignment of the arthrodesis had no significant influence on the union rate.

A multivariate logistic regression analysis was performed to identify the most important independent risk factors for non-union after first MTPJ arthrodesis. Diabetes was found to be the strongest risk factor for non-union (odds ratio 7.4; P= .019). A postoperative residual hallux valgus deformity represented the second strongest risk factor for first MTPJ non-union (odds ratio 6.5; P = .015). The non-union rate for patients with a postoperative residual hallux valgus deformity (HVA ≥ 20 degrees) was 20.7% (6/29) compared to 3.4% (5/149) in patients with a normal postoperative HVA. In patients with a severe preoperative hallux valgus deformity (HVA > 40 degrees), the non-union rate was 12.8% (5/39), whereas 4.3% (6/139) of the less severe cases developed a non-union. However, the effect of the preoperative hallux valgus deformity was no longer significant in the multivariate model (P= .519).

A dorsal locking plate combined with a separate compression screw showed a non-significant tendency towards lower non-union rates (4/81, 4.9%) compared to the dorsal locking plate with the incorporated compression screw (7/97, 7.2%; P= .76). All 4 non-unions in the former group showed a residual postoperative hallux valgus deformity of 20° or more. In the latter group, 1 of 7 non-unions had a residual postoperative hallux valgus deformity, 1 of 7 non-unions was associated with diabetes, and 1 of 7 non-unions had a combination of both risk factors. After exclusion of the cases with concurrent diabetes or residual hallux valgus deformity of 20° or more, the overall non-union rate was 2.9% (4/136). No cases (0/61) in the dorsal locking plate and separate compression screw group showed a non-union, whereas 4 of the 76 cases (5.3%) with a dorsal locking plate and incorporated compression screw had a non-union (P=. 13).

﻿**DISCUSSION**

Various operative techniques for first MTPJ arthrodesis have been described including one or two compression screws, locking and non-locking plates with or without an additional compression screw, and staples.3,7,18,20,26,28,37 Biomechanical studies exhibited that the combination of a dorsal plate with a compression screw leads to the stiffest arthrodesis construct among the mentioned techniques.5,22,31 Furthermore, Hunt et al. showed in a cadaveric study that locking plates lead to significantly less plantar gapping and significant higher load-to-failure stiffness than non-locking plates.24

Despite the outlined biomechanical advantages of plates for first MTPJ fusion, none of the fixation techniques have demonstrated any clear superiority in the clinical results.9,15 Bennett et al. evaluated 95 patients who had undergone 107 first MTPJ fusions with a dorsal non-locking titanium plate and a separate 2.4 mm compression screw and found a non-union rate of 13%.3 All non-unions were associated with hardware failure of either the plate or the compression screw. The authors concluded that the applied titanium plate might not have been strong enough. ﻿ Hunt et al. also reported higher non-union rates for locking titanium plates than non-locking stainless steel plates (16 of 73, 23% vs. 13 of 107, 12%; P< .06).25 The difference in non-union rates became significant when removing rheumatoid cases (21% vs. 6%, P< .05). The authors explained the higher non-union rates with insufficient ﻿interfragmentary compression with the locking design and lower rigidity of the titanium plate. However, the higher non-union rates may have also been caused by selection bias. Plate selection was at the discretion of the surgeons who presumably preferred locking plates in osteoporotic bone. In contrast, Doty et al. prospectively evaluated 48 first MTPJ arthrodeses with a titanium locking plate and a separate compression screw and reported only one non-union (2%).18 Wanivenhaus et al. retrospectively analyzed 41 first MTPJ arthrodeses with a locking plate made from a cobalt chrome alloy and a compression screw. At the 6-week follow-up, CT scans revealed a mean joint bridging of 54%, with 93% showing partial consolidation. In total, 7% developed a non-union, of which one was due to infection.36 Hyer et al. compared 4 different types of plating techniques: static plate alone, static plate with compression screw, locking plate alone, locking plate with compression screw. The overall non-union rate was 7% (9 of 138), with the lowest non-union rate after locking plate with compression screw (4%, 2 of 45). ﻿However, the differences in the results were not statistically significant (P> .05).27 In a retrospective study, Cone et al. reviewed 99 first MTPJ arthrodeses with either a dorsal locking plate alone or a dorsal locking plate with a separate compression screw.10 The overall non-union rate was 4%, with no significant difference between the two groups. However, the group with the compression screw showed significantly less change in the first MTPJ dorsiflexion angle during the postoperative period (0.6° vs. 6.7°, P< .01), suggesting that the addition of such a screw provides a more stable construct than a locking plate alone.

A meta-analysis included 26 studies with 2059 first MTPJ arthrodeses and reported an overall non-union rate of 6.5%.29 Significant lower non-union rates were achieved with a manual joint preparation technique (P< .0001) and in patients with hallux rigidus as the primary pathology (P= .003). ﻿The authors found no significant difference in non-union rates when comparing plate fixation to screw fixation (5.9% vs. 7.3%; P = .37). However, the locking plate group was not further analyzed for the use of an additional compression screw.

In this study, we evaluated possible risk factors for non-union in a larger consecutive cohort of patients who had undergone first MTPJ arthrodesis with a dorsal locking plate construct with either an incorporated compression screw or a separate compression screw. Our overall non-union rate was 6.2%, which is comparable to the published literature.29,33

the strongestindependentlA residual hallux valgus angle of 20 degrees or more is also an independent risk factor for the development of non-union after first MTPJ arthrodesis (odds ratio 6.5; P = .015). This finding has not been reported in any previous study. Therefore, correction of such a hallux valgus deformity is an important variable to reduce the risk of non-union after first MTPJ arthrodesis.

The senior authors changed their implants in 2017, due to a theoretical improvement of axial deforming forces in hallux valgus by using a separate oblique compression screw outside of the plate construct, 90 degrees to the plate position in the sagittal plane. We found that there was a tendency of a lower non-union rate with a dorsal locking plate combined with a separate compression screw than the incorporated compression screw and plate construct, however this did not reach significance(7.2 % vs. 4.9%, P= .756). After excluding all cases with diabetes or a residual postoperative hallux valgus deformity, the group with the locking plate and a separate compression screw showed a 100% union rate, whereas the group with an incorporated compression screw still had 4 non-unions (5.3%). This difference also did not reach significance (P= .13). Conversely, Latif et al. found a 100% union rate in 40 consecutive primary first MTPJ arthrodeses using the same plating system with incorporated compression screw of the present study.30

Several studies showed that even severe hallux valgus deformity can be adequately corrected with first MTPJ arthrodesis without an additional proximal metatarsal osteotomy.6,32,35 Sung et al. found a comparable non-union rate of 5.1% after first MTPJ arthrodesis using 3 different fixation techniques in 58 patients with preoperative hallux valgus deformity, of which 81% showed moderate to severe deformity.35 Chien et al. performed first MTPJ fusion with a dorsal plate and compression screw in severe hallux valgus (n=47) and hallux rigidus (n=65) and found no significant difference in the non-union rates (0% vs. 1.5%).6 Korim et al. showed that severe preoperative hallux valgus deformity is an independent risk factor for developing a non-union after first MTPJ arthrodesis.28 However, they did not provide any information on the postoperatively achieved correction of the hallux valgus deformities.

Our results also revealed the preoperative hallux valgus deformity to be a significant risk factor, which however, disappeared when adjusting for the postoperative residual hallux valgus deformity. This shows that not the degree of the preoperative deformity, but its insufficient postoperative correction is an independent risk factor for developing a non-union after first MTPJ arthrodesis.

Regarding the sagittal alignment of the first MTPJ arthrodesis, most studies recommended a target DFA of 15 to 25 degrees.12,14,16,34 Bayomy et al. showed in a cadaver study that pressure measurements inversely increased under the hallux and decreased under the metatarsal head; ﻿peak pressure and pressure-time integral under the forefoot were minimized at 24.7 degrees and 21.3 degrees, respectively.2 We are not aware of any studies that investigated the impact of the DFA on first MTPJ union rates. In our study, the mean DFA was 25 degrees but showed a great variety, ranging from 9 degrees to 44 degrees. Larger or smaller DFAs outside the recommended range did not lead to an increased non-union rate. Therefore, in contrast to the coronal plane deformity, the sagittal alignment does not play a role in achieving union.

Different joint preparation techniques have been described. In a meta-analysis, manual tools (e.g., rongeur, curette) led to significantly higher union rates than the use of power tools (e.g., cup and cone reamer, saws). No statistical differences were found in the union rates when comparing flat cut surfaces with ball-and-socket shaping.29 In this study, the use of either manual tools or cup and cone reamers showed no significant difference in the non-union rate.

Furthermore, we could not find any demographical risk factors that significantly influence the non-union rate. Hope et al. showed a significantly higher non-union rate in males23, which is in contrast to our study, where all non-unions were found in females. Our results probably did not reach significance as the majority of patients in this study group were females. Larger sample sizes are needed to reveal any gender differences.

This study has several limitations. The most important limitation derives from the retrospective study design, which relies on accurate data collection. Therefore, all the data obtained for the analysis can only be as good as the medical records documentation. Furthermore, the study lacks any patient-reported outcome measures. However, the main aim was to analyze the potential risk factors that lead to first MTPJ non-union. ﻿Although we attempted to ensure a standardized preoperative and postoperative weightbearing foot radiographs, some variations in foot position may have occurred and led to measurement bias. Finally, we cannot ascertain if the 3 non-unions associated with a break of the arthrodesis plate were caused by the implant failure or vice versa. We therefore decided to include these cases in the analysis.

**CONCLUSION**

Diabetes is the most important independent risk factor for non-union after first MTPJ arthrodesis with a dorsal locking plate and compression screw construct. A residual postoperative hallux valgus deformity is associated with a significantly increased risk for non-union. It is therefore crucial to correct the hallux valgus deformity to a hallux valgus angle of less than 20°.

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