Article

AMERICAN ORTHOPAEDIC FOOT & ANKLE SOCIETY

Foot & Ankle Orthopaedics
2020, Vol. 5(4) 1-7
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DOI: 10.1177/2473011420960710
journals.sagepub.com/home/fao

Distal Chevron Osteotomy Increases Anatomic Intermetatarsal Angle in Hallux Valgus

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Abstract

Background: Distal chevron metatarsal osteotomy (DCO) is a common technique to address hallux valgus (HV), which involves coronal translation of the capital fragment resulting in a nonanatomic first metatarsal. The purpose of this study was to evaluate the radiographic effect of the DCO on the anatomic vs the mechanical axis of the first metatarsal. Our hypothesis was that patients undergoing DCO would have improvement in the mechanical metatarsal axis but worsening of the anatomic axis.

Methods: This was a retrospective case series of consecutive patients who underwent DCO for HV. The primary outcomes were the change in anatomic first–second intermetatarsal angle (a1-2IMA) vs mechanical first–second intermetatarsal angle (m1-2IMA). Secondary outcomes included the change in hallux valgus angle (HVA) and medial sesamoid position.

Results: 40 feet were analyzed with a mean follow-up of 21.2 weeks. The a1-2IMA increased significantly (mean, 4.1 degrees) whereas the m1-2IMA decreased significantly (mean, 4.6 degrees) following DCO. There was a significant improvement in HVA (mean, 12.5 degrees). Medial sesamoid position was improved in 21 feet (52.5%). Patients with no improvement in sesamoid position were found to have a larger increase in a1-2IMA (mean, 4.7 vs 3.5 degrees, $P = .03$) and less improvement in m1-2IMA (mean, 3.8 vs 5.2 degrees, $P = .02$) compared to patients with improvement in sesamoid position.

Conclusion: Distal chevron osteotomy for HV was associated with worsening of the anatomic axis of the first metatarsal despite improvements in the mechanical metatarsal axis, HVA, and medial sesamoid position. Greater worsening of the anatomic axis was associated with less improvement of sesamoid position. Our findings may suggest the presence of intermetatarsal instability, which could limit the power of DCO in HV correction for more severe deformities and provide a mechanism for HV recurrence.

Level of Evidence: Level IV, retrospective case series.

Keywords: chevron osteotomy, hallux valgus, intermetatarsal angle, metatarsal instability

Introduction

More than 130 different techniques have been described for operative correction of symptomatic hallux valgus (HV),[26] with each having various strengths and limitations. Distal chevron osteotomy (DCO) of the first metatarsal is one of the most commonly used techniques to address mild to moderate HV deformity.[23,24] Advantages include the intrinsic geometric stability of the osteotomy, low invasiveness of the procedure, and minimal metatarsal shortening.[7,31] Prior studies have validated its clinical effectiveness and

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shown favorable patient satisfaction and functional outcomes.[16,30,31]

In the uniplanar form, DCO involves lateral displacement of the distal first metatarsal head relative to the metatarsal shaft. Because of the coronal translation of the capital fragment resulting in a nonanatomic first metatarsal, prior studies reporting outcomes following DCO have measured radiographic correction of HV using primarily the mechanical axis of the first metatarsal. Despite the improvement in mechanical axis, we have observed an opposing medial shift of the first metatarsal shaft during DCO. This observation is clinically relevant as worsening of the anatomic axis of the first metatarsal may theoretically limit the power of the DCO in more severe HV deformities. In addition, medial shifting of the first metatarsal into further adduction could be a potential mechanism for HV recurrence, which has been noted to range from 10% to 15% in short-term studies,[1,11,15] to nearly 75% at long-term follow-up.[10,22]

However, there has been little investigation to quantify the effect of DCO on the anatomic axis of the first metatarsal. The primary purpose of this study was to evaluate the radiographic effect of DCO on the anatomic axis of the first metatarsal compared to the first metatarsal mechanical axis. The secondary purpose was to assess the change in hallux valgus angle (HVA) and medial sesamoid position. Our hypothesis was that patients undergoing DCO would have improvement in the mechanical first metatarsal axis but worsening of the anatomic axis. We also hypothesized that patients with a greater medial shift of the anatomic axis would obtain less correction of their mechanical first metatarsal axis.

Methods

After obtaining review and approval of the institutional review board, a retrospective chart review was performed on all consecutive patients between 16 and 90 years of age who underwent a DCO for symptomatic hallux valgus correction between January 2017 and December 2019 by a single foot and ankle fellowship–trained surgeon at an academic tertiary care institution. The inclusion criteria for this study required patients to have undergone DCO for the diagnosis of symptomatic hallux valgus with preoperative as well as postoperative weightbearing AP and lateral radiographs of the foot. There was no preoperative radiographic deformity cutoff value, but the senior surgeon generally restricts the use of DCO for patients with mild to moderate hallux valgus deformities (intermetatarsal angle of 14 degrees or less). Patients were excluded if any prior procedures were performed for hallux valgus correction, if there was an associated foot deformity such as a planovalgus deformity, if there was loss of fixation postoperatively, or if they developed a nonunion or avascular necrosis of the metatarsal head following DCO. Patients were also excluded if there was any documented evidence of first ray sagittal instability based on clinical exam or the presence of plantar gapping at the first tarsometatarsal joint on weightbearing lateral radiographs of the foot.

Fifty feet (43 patients) were identified for initial chart review who had undergone DCO for HV during the study period. Eight feet were excluded for having incomplete preoperative or postoperative imaging. One foot was excluded for having an associated severe planovalgus foot deformity. One foot was excluded for having a prior Lapidus procedure for HV. A total of 40 feet (36 patients) were included for final analysis. The mean age of the study cohort was 53.2 years (range, 16-81) and the mean body mass index was 24.2 (range, 15.9-36.9) at the time of surgery. Of the 36 patients, there were 5 males (5 feet) and 31 females (35 feet). Twenty-one DCO procedures were performed on the left foot and 19 procedures were performed on the right. In regard to concomitant procedures at the time of hallux valgus correction, 23 feet underwent Akin osteotomy of the proximal phalanx, 10 feet underwent hammertoe correction, 4 feet had shortening osteotomies of the lesser metatarsals, and 5 feet underwent bunionette correction. Final radiographs were obtained at a mean of 21.2 weeks (range, 5-119) postoperatively.

To evaluate the effect of DCO on the anatomic axis of the first metatarsal, the change in anatomic first–second intermetatarsal angle (a1-2IMA) was measured between preoperative to postoperative weightbearing AP foot radiographs. The a1-2IMA was defined as the difference between the longitudinal diaphyseal axis of the first and second metatarsals. To assess change in the mechanical axis of the first metatarsal following DCO, the mechanical first–second intermetatarsal angle (m1-2IMA) was measured. The m1-2IMA was calculated as the difference between the mechanical axis of the first and second metatarsals, which was defined as the axis connecting the center of the metatarsal head to the center of the metatarsal base (Figure 1). Secondary radiographic outcomes that were also measured included the change in HVA as well as the medial sesamoid position, using the grading scale described by Talbot et al.[29] In addition, given the relatively high prevalence of metatarsus adductus in hallux valgus patients, the modified Engel metatarsus adductus angle was measured on AP radiographs.[2] Patients were classified as having metatarsus adductus if the metatarsus adductus angle was greater than or equal to 24 degrees, as described previously.[2] Finally, to control for any inconsistencies in radiographic technique, the change in second–third intermetatarsal angle (2-3IMA), defined by the diaphyseal metatarsal axis, was measured. All radiographic measurements were performed with the use of a picture archiving and communication system (PACS, Hyland Healthcare, Westlake, OH) software.

Operative Technique

An approximately 4-cm-long medial longitudinal approach with full thickness skin flaps was used to approach the medial capsule of the first metatarsophalangeal joint. A medial L-shaped capsulotomy was then performed with the vertical

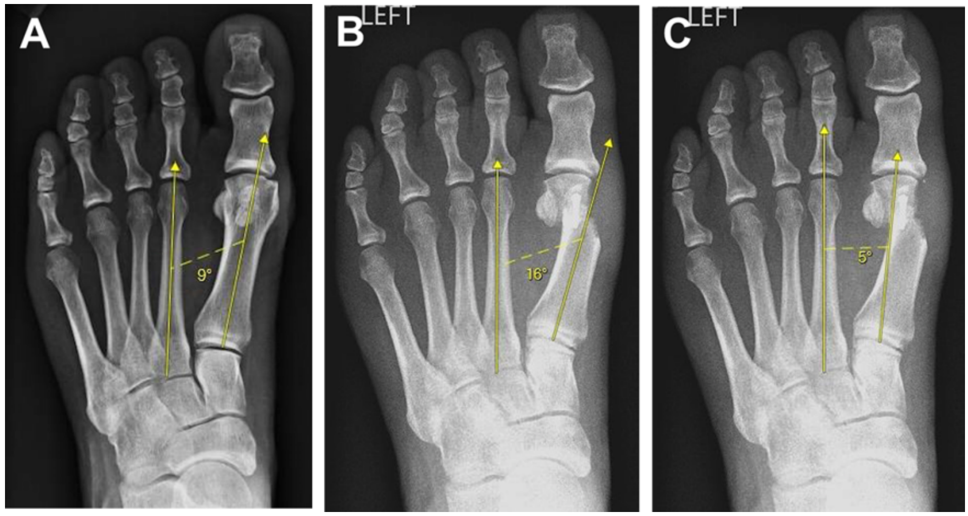

Figure 1. Postoperative anteroposterior radiographs of the foot following distal chevron osteotomy for symptomatic hallux valgus correction. (B) The anatomic first–second intermetatarsal angle (a1-2IMA) was defined as the difference between the diaphyseal axis of the first and second metatarsals. (C) The mechanical first–second intermetatarsal angle (m1-2IMA) was defined as the difference between the mechanical first and second metatarsal axes, drawn from the center of the metatarsal head to the center of the metatarsal base. (A) This patient was noted to have an increase in the a1-2IMA of 7 degrees and a decrease in the m1-2IMA of 4 degrees from a preoperative intermetatarsal angle of 9 degrees.

limb just proximal to the joint and a dorsal horizontal limb extending proximally to the level of the distal metaphysis. After medial eminence resection was performed just medial to the sagittal sulcus, the DCO was performed centered on the metatarsal head with the plantar limb exiting just proximal to the metatarsal articular surface. Once the osteotomy cuts were completed, the distal metatarsal head was manually translated laterally and the osteotomy was provisionally pinned with a Kirschner wire. Following fluoroscopic confirmation of adequate correction, the osteotomy was then fixed with a 2.5-mm screw from dorsal to plantar. Lateral soft tissue release was not performed by the senior surgeon in combination with DCO for hallux valgus. Following DCO, an Akin osteotomy was performed at the discretion of the surgeon based on residual deformity or the presence of hallux valgus interphalangeus. The same medial approach was used to access the proximal phalanx. A medial-based closing wedge osteotomy was then performed at the metaphyseal region and fixated using 3-0 Nylon suture through bone tunnels. The medial capsule was then tightened by excising a V-shaped wedge from the capsulotomy flap prior to closure.

Postoperatively, all patients were placed in a bunion dressing and made heel weightbearing in a hard-soled postoperative shoe. Following suture removal at 2 weeks, patients were instructed to transition to weightbearing as tolerated on the operative foot by the 4-week postoperative mark. Once fully weightbearing, patients were encouraged to return to regular shoewear as tolerated. Standard radiographic follow-up included weightbearing foot radiographs at 6 weeks and 3 months. Patients were not routinely asked to follow-up beyond 3 months if they were recovering well clinically.

Statistical Analysis

Based on reported data from 2 prior studies investigating the effect of DCO on metatarsal axis,[3,19] we estimated a standardized effect size of 3 degrees with a standard deviation of 3 degrees. Using this effect size, assuming a 2-sided 0.05 alpha level, a total cohort size of 32 patients would be required to detect the stated difference with 80% power using an independent study group design and a continuous endpoint. Given the relatively small patient cohort, nonparametric Wilcoxon signed-rank test and Mann-Whitney *U* test were used for statistical analysis. With both of these tests, *P* values less than or equal to .05 were considered statistically significant. All statistical analyses were performed using SAS software version 9.2 (SAS Institute, Cary, NC).

Results

There was a significant increase (mean, 4.1 degrees, $P < .001$) in the a1-2 IMA from a mean of 10.9 degrees (range, 8-14) preoperatively to 15.0 degrees (range, 9-19) postoperatively. For the m1-2IMA, there was a significant decrease (mean, 4.6 degrees, $P < .001$) from a mean of 10.9 degrees (range, 8-14) preoperatively to 6.4 degrees (range, 1-11) postoperatively. The HVA improved from a mean of 21.0 degrees (range, 12-38) preoperatively to 8.5 degrees (range, 1-15) postoperatively, which represented a significant decrease of 12.5 degrees ($P < .001$). No changes were found in the 2-3IMA (mean, 0.1 degrees, $P = .83$) (Table 1).

Table 1. Radiographic Changes Following Distal Chevron Osteotomy.

	Preoperative, Mean ± SD or n (%)	Postoperative, Mean ± SD or n (%)	Change	*P* Value
Anatomic 1-2 IMA, degrees	10.9 ± 1.8	15.0 ± 2.5	4.1	<.001
Mechanical 1-2 IMA, degrees	10.9 ± 1.8	6.4 ± 1.9	–4.6	<.001
2-3 IMA, degrees	1.6 ± 1.4	1.7 ± 1.5	0.1	.834
Hallux valgus angle, degrees	21.0 ± 5.7	8.5 ± 3.8	–12.5	<.001
Medial sesamoid station,[a] n (%)				
Grade 1	6 (15)	26 (65)		
Grade 2	33 (83)	14 (35)		
Grade 3	1 (2)	0		

Abbreviation: IMA, intermetatarsal angle.
[a]Based on grade scale in Talbot et al.[29]

Sixteen patients were found to have a change in a1-2IMA greater than 4 degrees and 24 patients with a change ≤4 degrees. There was a trend toward a higher residual postoperative m1-2IMA (mean, 7.1 vs 5.9 degrees, $P = .06$) among patients with a change in a1-2IMA above 4 degrees, which did not reach statistical significance.

Preoperatively, 6 patients were noted to have a grade 1 sesamoid station, 33 patients with a grade 2 sesamoid station, and 1 patient with a grade 3 sesamoid station. Postoperatively, there were 26 patients with a grade 1 sesamoid station, 14 patients with a grade 2 sesamoid station, and no patients with a grade 3 sesamoid station (Table 1). There was improvement in the sesamoid station in 21 feet, which represented 52.5% of the cohort. Patients with no change in medial sesamoid position were noted to have a significantly greater increase in a1-2IMA (mean, 4.7 vs 3.5 degrees, $P = .03$) and significantly less improvement in m1-2IMA (mean, 3.8 vs 5.2 degrees, $P = .02$) compared to patients with improved sesamoid position.

Ten patients (25%) were found to have a radiographic metatarsus adductus deformity of the foot. There was no difference in the change in a1-2IMA (mean, 4.2 vs 3.5 degrees, $P = .47$) between normal and metatarsus adductus patients. There was no difference in the change in a1-2IMA (mean, 3.9 vs 4.3 degrees, $P = .47$) or m1-2IMA (mean, 4.3 vs 4.8 degrees, $P = .41$) between patients who underwent concomitant Akin procedures compared to patients who did not. There was no difference in the change in a1-2IMA (mean, 3.9 vs 4.1 degrees, $P = .87$) between patients with radiographic follow-up greater than 12 weeks (19 feet) compared to those with less than 12 weeks (21 feet).

Discussion

Prior literature regarding DCO has primarily reported on improvement of the mechanical axis of the first metatarsal and HVA in the correction of hallux valgus. This study evaluated the effect of DCO on the anatomic axis of the first metatarsal in comparison to these traditional radiographic measures of HV. Our findings revealed that DCO is associated with a significant increase in the anatomic intermetatarsal angle despite improvements in the mechanical metatarsal axis and HVA, which is a novel finding. Furthermore, a larger increase in the anatomic intermetatarsal angle following DCO was associated with less correction in sesamoid position. The residual postoperative mechanical intermetatarsal angle was noted to be higher in patients with a greater increase in anatomic intermetatarsal angle, but this did not reach statistical significance.

Two studies have previously reported on the change in anatomic axis of the first metatarsal following DCO for HV and found improvement in the a1-2IMA. Bai et al evaluated a series of 86 feet following DCO with a concurrent lateral soft tissue release and found a mean reduction of 2.7 degrees in a1-2IMA.[3] Similarly, Oloff et al[19] reported an average of 5.2 degrees reduction in a1-2IMA following DCO in a small series of 13 feet. In contrast, our study demonstrated a mean increase of 4 degrees in a1-2IMA following DCO. It is notable that both of these previous studies evaluated patients with significantly greater HV deformities with a mean preoperative intermetatarsal angle of greater than 17 degrees compared to an average of 11 degrees in our study. If the observed adduction of the first metatarsal shaft occurs through coronal motion at the first tarsometatarsal joint, it is possible that more severe HV deformities may have exhausted the physiologic motion at the joint, which would limit any further widening of the a1-2IMA. This may explain the comparable final postoperative a1-2IMA between Bai et al and this study (mean, 14.4 vs 15.0 degrees) despite opposite changes in the first metatarsal anatomic axis.

The observed increase in a1-2IMA following DCO is likely due to the nonanatomic lateral position of the metatarsal head on the metatarsal shaft. Axial loading of the lateralized head would result in a medially directed force on the metatarsal shaft and lead to medial adduction of the anatomic axis of the first metatarsal. The presence of metatarsus adductus could potentially predispose patients to further adduction of the metatarsal shaft and has been found to be common among hallux valgus patients.[2] However, we did not identify any differences in the change in a1-2IMA between patients with radiographic evidence of metatarsus adductus compared to normal patients.

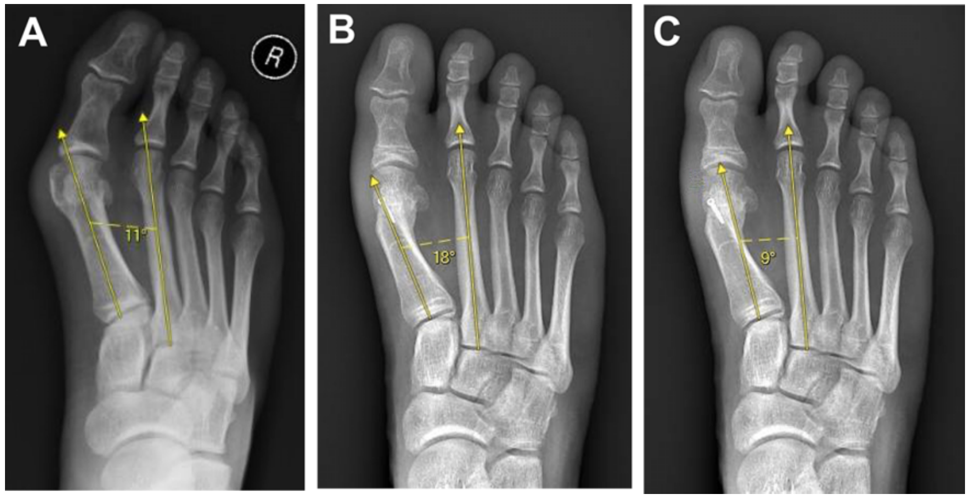

Figure 2. Postoperative anteroposterior radiographs of the foot following distal chevron osteotomy for hallux valgus correction in a patient with incomplete sesamoid reduction. (B) This patient was noted to have an increase in the anatomic first–second intermetatarsal angle (a1-2IMA) of 7 degrees from (A) a preoperative intermetatarsal angle of 11 degrees. (C) The large increase in a1-2IMA may have resulted in the relatively high final m1-2IMA of 9 degrees and incomplete sesamoid reduction.

There are 2 theoretical clinical implications of the apparent worsening in the anatomic first metatarsal axis following DCO. In our study, patients with a greater increase in the a1-2IMA trended toward having a larger residual deformity (wider final m1-2IMA) compared to patients with less change in the anatomic axis. This may represent incomplete correction of the fixed metatarsal head due to shifting of the metatarsal shaft into further adduction. When combined with the inherent physical limitations to lateral translation of the metatarsal head,[14,17] this may limit the utility of DCO for more severe HV deformities. The increase in a1-2IMA is also concerning as a potential mechanism for HV recurrence. Loss of correction of the intermetatarsal angle as well as HVA has been demonstrated in short-term follow-up within 3 months following DCO,[13] whereas the rate of HV recurrence has been reported to be as high as 73% in one series with 14-year follow-up.[10] The cause of recurrent HV is likely multifactorial but the described radiologic risk factors include greater preoperative deformity, incomplete reduction of the sesamoids, metatarsophalangeal joint incongruency, as well as first ray hypermobility.[12,18,21,22,25] Although we excluded any patients with radiographic evidence of first ray instability in this study, increasing the a1-2IMA effectively results in the presence of a metatarsus primus varus and could contribute to HV recurrence following DCO. However, further investigation is warranted to directly link HV recurrence to a change in the anatomic metatarsal axis.

Postoperatively, two-thirds of the patients in our study had "reduced" sesamoids as defined by Esemenli et al (sesamoid station of grade 1 or less), which is similar to prior studies evaluating sesamoid position following DCO.[3,4,8,17,27,28,33] Though most of the patients in the cohort had adequate sesamoid reduction, nearly half of the patients did not have significant improvement in sesamoid station. Sesamoid position has been shown to be correlated with postoperative functional outcomes and patient satisfaction[4] as well as maintenance of HV correction.[18,21] Several factors have been suggested that may affect sesamoid reduction, including correction of the mechanical first metatarsal axis, first ray pronation, as well as the use of a lateral soft tissue release. In our study, patients with no improvement in sesamoid station were associated with greater worsening of the anatomic axis and less improvement of the mechanical first metatarsal axis. This observation reinforces the possibility that the increase in a1-2IMA following DCO may result in a relative undercorrection of the mechanical metatarsal axis (Figure 2). Our operative technique did not involve an attempt to achieve sesamoid reduction by correcting first ray pronation, or by a lateral soft tissue release. Although the use of an HV correction procedure that addresses pronation, such as the modified Lapidus, or the addition of a lateral soft tissue release may have improved sesamoid position, several studies have found no correlation between first metatarsal pronation or the use of a lateral soft tissue release on final postoperative sesamoid position.[6,27,33]

Despite worsening of the anatomic axis of the first metatarsal, patients in our study cohort were found to have improvement of other radiographic measures for HV. The mean improvement of the m1-2IMA (4.6 degrees) and the mean postoperative m1-2IMA (6.4 degrees) is comparable to multiple prior studies evaluating DCO.[3,5,9,10,12,13,16,20,28,32] Similarly, the HVA was also noted to have significant improvement with a final average measurement of 8.5 degrees. This is consistent with the existing literature,[3,5,9,10,12,13,16,20,28,32] and expected given that the mechanical axis of the first metatarsal was used for the HVA measurement.

The current study has some limitations. This was a single surgeon retrospective case series using a single operative technique in a patient cohort with mild to moderate HV deformity. For severe HV deformities with high intermetatarsal angles, we typically use proximal metatarsal osteotomies rather than a DCO. This may limit whether our findings can be generalized to the treatment of more severe HV deformities. In addition, our operative technique involved an open medial approach without the use of a lateral soft tissue release. Therefore, it is unclear how the use of minimally invasive DCO techniques or the addition of a lateral soft tissue release would affect the a1-2IMA. We also did not control for the use of other concomitant procedures in the lesser toes during HV correction given that it would be unlikely that these procedures would have an effect on the first metatarsal axis. The use of an Akin procedure was evaluated and did not appear to affect the change in a1-2IMA despite being powered to assess an effect size of 3 degrees. Nevertheless, our patient cohort size may be underpowered to assess smaller effect sizes due to the Akin, as well as the potential effect of metatarsus adductus on the first metatarsal axis. Our study was also limited by short-term follow-up at a mean of 21 weeks. Longer-term follow-up may have allowed us to evaluate for HV recurrence and any correlation to changes in the anatomic first metatarsal axis. However, we do not routinely ask asymptomatic patients to return for long-term follow-up following HV correction. Moreover, we did not identify any difference in the change in a1-2IMA between patients with follow-up more than 3 months compared to those with less. Another limitation involved the use of 2-dimensional radiography to assess the change in first metatarsal axis. We attempted to control for variations in radiographic technique through the use of the 2-3IMA as a control measurement. There was no significant change in the mean 2-3IMA from preoperative to postoperative radiographs, which suggests that there was no systematic bias in radiographic technique. However, the use of weightbearing CT would have allowed for further control over radiographic evaluation. Weightbearing CT would also have allowed evaluation for potential rotational instability in the first tarsometatarsal joint that might have contributed to the observed changes in a1-2IMA. Finally, our study was purely radiographic and did not include any patient-reported outcomes. However, clinical outcomes following DCO have been studied extensively in the literature and we did not feel that the inclusion of patient-reported outcomes would have contributed additional new information.

Conclusion

Distal chevron osteotomy is a commonly used procedure for correction of mild to moderate HV deformities. Although the effect of DCO on the mechanical first metatarsal axis has traditionally been the focus, our study contributes to the body of knowledge by evaluating the change in anatomic first metatarsal axis. Our study found that there was an increase in the anatomic intermetatarsal angle despite improvements in traditional measures of HV correction such as the mechanical intermetatarsal angle, HVA and sesamoid station. In addition, a greater amount of worsening of the anatomic axis was associated with less improvement of sesamoid position. Our findings may suggest the presence of intermetatarsal instability, which could possibly account for the limitations of the DCO to correct more severe HV deformities and may provide a mechanism for HV recurrence in these patients.

Ethics Approval

Ethical approval for this study was obtained from the Office of Research Compliance and Quality Improvement at Cedars-Sinai Medical Center (ID#: Study00000473).

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: David B. Thordarson, MD, reports being Editor-in-Chief of *Foot & Ankle Orthopaedics*. 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.

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