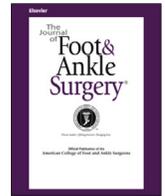




Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Should We Use Intermetatarsal Angle as Primary Determinant to Define the Limits of Distal Chevron Osteotomy?

Görkem Kiyak, MD¹, Tanil Esemeli, MD²¹ Orthopaedic Surgeon, Department of Orthopaedics and Traumatology, Academic Hospital, Istanbul, Turkey² Professor, Department of Orthopaedics and Traumatology, Academic Hospital, Istanbul, Turkey

ARTICLE INFO

Level of Clinical Evidence: 4

Keywords:

bone contact
chevron osteotomy
hallux valgus
intermetatarsal angle
stability

ABSTRACT

Classic treatment algorithms limit the use of distal chevron osteotomy (DCO) to cases with an intermetatarsal angle (IMA) $<14^\circ$. As the IMA increases, it is accepted that the contact between the metatarsal head and shaft will be insufficient. We have investigated the reliability of IMA to predict contact area percentage after DCO. Preoperative radiographs of patients with hallux valgus were subdivided as mild, moderate, and severe using traditional algorithms. After excluding the mild cases, we randomly selected 100 patients (50 moderate and 50 severe) and calculated the estimated bony contact (EBC) with our method and investigated the percentage of patients who could have $>50\%$ contact area if we perform a DCO. Thirty of 50 (60%) and 17 of 50 (34%) patients had $>50\%$ EBC in moderate and severe groups, respectively. We performed DCO for 24 patients (14 moderate and 10 severe cases). The 100-point American Orthopaedic Foot and Ankle Society (AOFAS) hallux-metatarso-phalangeal-interphalangeal scale was used to assess the clinical outcome. For the moderate group, we calculated mean IMA 16° (standard deviation [SD] $\pm 1.4^\circ$) and mean EBC 66.9% (SD $\pm 10.8\%$). For the severe group, we calculated mean IMA 20.9° (SD $\pm 0.7^\circ$) and mean EBC 63.1% (SD $\pm 10.4\%$). Paired *t* tests showed significant improvement comparing preoperative and postoperative AOFAS scores, IMA, hallux valgus angle, and sesamoid position for all operated patients ($p < .001$). We did not see any recurrence of hallux valgus or hallux varus and had only 1 minor complication that we managed conservatively. IMA may not always be a reliable parameter to predict the stability of DCO. Because the stability depends on the contact surfaces of osteotomy fragments, metatarsal head diameter and remaining bone contact should be the primary concerns. Two patients with the same IMA can have a different contact surface varying on a broad spectrum.

© 2018 by the American College of Foot and Ankle Surgeons. All rights reserved.

Hallux valgus causes a painful bony prominence for patient, which makes shoe fit difficult. It is composed of 2 primary angular pathologies: (1) medial deviation of the first metatarsal bone, and (2) lateral deviation of the great toe. Hallux valgus deformities have been traditionally quantitated by measuring hallux valgus angle (HVA) and intermetatarsal angle (IMA). Widely accepted treatment algorithms have been based on these angular measurements (1,2).

According to these algorithms, the most popular technique, namely, distal chevron osteotomy (DCO), is suitable only for the cases with an IMA $<14^\circ$, and proximal, complex osteotomies, which are prone to complications, are recommended with a higher IMA. Because of its technical simplicity and stability allowing early ambulation and rapid healing, there have been some attempts to extend the indications of DCO.

Despite the promising results, the limits of a DCO to correct this common deformity are still not clear (3–5).

Although a tendency exists to widen the indications of distal metatarsal osteotomies, classic treatment algorithms based on angular measurements limit the use of distal metatarsal osteotomies to cases with an IMA $<14^\circ$, assuming only 4 to 6 mm of displacement, which is equivalent to 4° to 6° of correction, is possible at this level (6–8). As the IMA increases, it is accepted that the contact between the metatarsal head and shaft will be insufficient and complications will occur. In geometric terms, the improvement obtained in the distal angulation between the first and the second metatarsals will correspond to the magnitude of the lateral shift. It is stated that a 1° improvement in angulation will take place with a 1-mm shift of the metatarsal. Although this dictum implies that a deformity $>14^\circ$ cannot reestablish the alignment, such limitation is not supported in clinical practice and does not consider the variance of the width of the metatarsal head (9).

In this study, we investigated patients on whom we planned to operate for hallux valgus. We used a new measurement technique

Financial Disclosure: None reported.**Conflict of Interest:** None reported.

Address correspondence to: Görkem Kiyak, MD, Department of Orthopaedics and Traumatology, Academic Hospital, Nuhkuyusu cad. 94, Istanbul, Turkey 34664.

E-mail address: drgorkemkiyak@gmail.com (G. Kiyak).

independent from IMA, which we developed to predict the amount of minimum lateral shifting distance and the contact percentage after shifting the metatarsal head. Greater contact surface provides stability on osteotomy lines. The purpose of this study is to investigate the reliability of IMA to predict the contact surface after metatarsal osteotomy.

Patients and Methods

Between January 2014 and January 2018, patients with symptomatic hallux valgus were randomly selected and followed up in this study. We used preoperative standing radiographs of patients for whom we advised surgical correction. According to standard practice, we subdivided patients as mild, moderate, and severe hallux valgus using angular radiologic measurement of IMA. We excluded the patients with mild hallux valgus ($\text{IMA} < 14^\circ$) as described by Robinson and Limbers (1). Table 1 shows the standard criteria for classification.

After excluding the mild cases, we randomly selected radiographs of patients from moderate and severe groups and formed 2 groups equal in number: 50 patients (14 [28%] male, 36 [72%] female) in the moderate group and 50 patients (12 [24%] male, 38 [76%] female) in the severe group. Then we calculated the estimated bony contact (EBC) with our method and investigated the percentage of patients who could have $>50\%$ contact area and, therefore, a stable osteotomy if we performed a DCO. Thirty of 50 (60%) and 17 of 50 (34%) patients had $>50\%$ EBC in moderate and severe groups, respectively.

We excluded patients with congenital deformities of the foot; hallux rigidus (metatarsophalangeal joint dorsiflexion $\leq 55^\circ$); tarsometatarsal joint instability and or hypermobility; previous first ray trauma or foot and ankle surgery; or diagnosis of rheumatic, dysmetabolic, neurologic, infective, or psychiatric pathologies for operation. In rare cases with metatarsus adductus, IMA is not reliable, so we excluded patients with metatarsus adductus. Then we performed DCO on patients who accepted surgery. We operated on 24 patients whose preoperative EBC was $>50\%$: 14 [58.3%] moderate (4 [28.5%] male, 10 [71.5%] female) and 10 [41.7%] severe (4 [40%] male, 6 [60%] female) cases. Patients in the study have a minimum of 2 years of follow-up records after surgery.

Ages of patients ranged from 26 to 72 years. The 100-point American Orthopaedic Foot and Ankle Society (AOFAS) hallux-metatarso-phalangeal-interphalangeal scale was used to assess clinical outcomes, and preoperative and postoperative AOFAS scores were recorded for further statistical evaluation (10,11). We also recorded preoperative and postoperative complications such as infection, hallux varus, recurrence, etc.

We allowed the patients to walk after the first day with an offloading shoe. After 3 weeks, we allowed them to bear weight partially, and after 6 weeks full weightbearing was allowed. Radiographic evaluation was performed preoperatively, 1 week and 3 months postoperatively, and at the time of the last follow-up visit. All radiographs were taken in a weightbearing position. Measurements were performed on the preoperative and last follow-up radiographs.

Surgical Technique

A Y-shaped incision was made on the first metatarsophalangeal joint, and a lateral soft-tissue release was undertaken through the same incision. The medial eminence remained intact, and the osteotomy was fashioned with a saw. The apex of the osteotomy was centered 3 to 5 mm superior to the geometric center of the metatarsal head. The plantar cut was made more horizontal than a classic DCO, resulting in an extended plantar limb. The plantar cut was also directed slightly plantar in the medial to lateral direction. The dorsal cut was made more vertical and directed perpendicular to the second metatarsal in the axial plane. After displacement of the distal fragment, the osteotomy was fixed with one or two 2.7-mm headless cannulated compression screws. Prominent bone ridges were excised, and a medial capsulorrhaphy was performed.

A New Preoperative Surgical Measurement

Preoperatively, we measured the metatarsal head diameter at its widest portion (A) and marked the lateral cortex at this level (x) and marked where we wanted to see the lateral cortex of the metatarsal head after the operation (y) on standing anteroposterior radiograph (Fig. 1). Then we measured the distance between x and y to determine the amount of displacement required (B) to correct the deformity. We drew another line through the soft tissue shadow of the hindfoot anteriorly (C) to determine if this amount of displacement would still leave a bony prominence at the forefoot on the medial side, which is the primary concern of the patients with this disorder. This is especially important for the cases with metatarsus adductus, where a small space exists between the first

Table 1

Classification of hallux valgus according to angular measurements

	Coughlin et al (2), 2007	Robinson and Limbers (1), 2005
Mild	HVA $< 30^\circ$; IMA $< 13^\circ$	IMA $< 14^\circ$
Moderate	HVA $< 40^\circ$; IMA $> 13^\circ$	$14^\circ < \text{IMA} < 20^\circ$
Severe	HVA $> 40^\circ$; IMA $> 20^\circ$	IMA $> 20^\circ$

Abbreviation: HVA, hallux valgus angle; IMA, intermetatarsal angle.



Fig. 1. Anteroposterior radiograph: Metatarsal head diameter at its widest portion (A), the lateral cortex of the metatarsal head at this level (x) and where lateral cortex needed to be to bring the metatarsal head over the sesamoids to obtain an anatomic correction (y), and amount of expected displacement (B). C refers to the line drawn through the soft tissue shadow on the medial side of the hindfoot to determine if a medial bony prominence will remain after the lateral displacement in the forefoot.

and second metatarsals and makes it difficult to achieve an adequate correction. If both seemed satisfactory, we inspected the EBC after the displacement, namely $A-B$ and its percentage to the head diameter $(A-B)/A$.

Radiographic Measurements

All radiographs were made at our facility and according to the same radiographic protocol. Weightbearing dorsoplantar radiographs of patients were used. The IMA was defined as the angle between the longitudinal axis of the first and that of the second metatarsal. The longitudinal axis of the proximal phalanx and that of the second metatarsal was defined as the line connecting the centers of the proximal and distal ends of the diaphysis (12).

Results

For the moderate group, 30 of 50 (60%) patients had $>50\%$ EBC. We operated on 10 of these patients and before operations calculated the mean IMA 16° (standard deviation [SD] $\pm 1.4^\circ$) and the mean EBC 55.58% (SD $\pm 17.08\%$). For the severe group, 17 of 50 (34%) patients had $>50\%$ EBC. We operated on 10 of these patients and before operations calculated the mean IMA 20.9° (SD $\pm 0.7^\circ$) and the mean EBC 66.9% (SD $\pm 10.8\%$).

Table 2 shows the pre- and postoperative results of the groups. All statistical analysis was conducted using SPSS software version 21.0 (Statistical Package for Social Sciences, IBM Corp., Armonk, NY). The paired *t* test was applied to analyze the differences. A *p* value (probability of the null hypothesis) $\leq .05$ was considered statistically significant.

Paired *t* tests showed statistically significant improvement comparing preoperative and postoperative AOFAS scores, IMA, HVA, and sesamoid position of moderate, severe, and all patient subgroups ($p < .001$). Unpaired *t* tests showed that the difference is not statistically significant between moderate and severe subgroups when we compare postoperative AOFAS scores, IMA, HVA, and sesamoid position ($p < .05$). Also, the

Table 2
Radiographic results and american orthopaedic foot and ankle society scores

	Moderate (14 Patients)	Severe (10 Patients)	All Patients (24 Patients)
HVA (°)			
Preoperative	34.5 ± 2.98 (32.77, 36.22)	42.9 ± 2.2 (41.3, 44.49)	38 ± 4.9 (35.89, 40.1)
Postoperative	6.2 ± 2.08 (5.01, 7.41)	6.9 ± 2.1 (5.37, 8.42)	6.5 ± 2.08 (7.61, 7.38)
IMA (°)			
Preoperative	16 ± 1.4 (15.15, 16.84)	20.9 ± 0.7 (20.37, 21.42)	18 ± 2.7 (16.88, 19.2)
Postoperative	5.1 ± 1.5 (4.27, 6.01)	6.3 ± 1.3 (5.34, 7.25)	5.62 ± 1.5 (4.98, 6.27)
Sesamoid position (grade)			
Preoperative	4.9 ± 0.8 (4.45, 5.4)	6.1 ± 0.7 (5.57, 6.62)	5.4 ± 0.9 (5.0, 5.82)
Postoperative	2.5 ± 0.6 (2.12, 2.87)	3.1 ± 1 (2.46, 3.93)	2.8 ± 0.9 (2.42, 3.16)
Mean AOFAS score			
Preoperative	43.85 ± 16.06 (34.58, 53.13)	37 ± 12.08 (28.35, 45.64)	41 ± 14.6 (34.8, 47.19)
Postoperative (48 months)	82.5 ± 10.7 (76.37, 88.77)	77.9 ± 6.2 (73.4, 82.39)	80.6 ± 9.2 (76.7, 84.54)
EBC before operation (%)	66.9 ± 10.8 (61.82, 72.3)	63.1 ± 10.4 (56.29, 70.15)	65.3 ± 10.6 (61.51, 69.36)

Abbreviation: AOFAS, American Orthopaedic Foot and Ankle Society; EBC, estimated bony contact; HVA, hallux valgus angle; IMA, intermetatarsal angle. Data are mean ± standard deviation (95% confidence interval).

bone contact percentage after lateral translation showed the difference is not statistically significant between moderate and severe subgroups ($p < .05$).

There was 1 minor wound complication. We did not see any recurrence of hallux valgus (HVA $>15^\circ$) or hallux varus. One patient had delayed union, which we managed conservatively. One patient had asymptomatic focal avascular necrosis on radiographs.

Discussion

Operations to correct hallux valgus deformity primarily aim to bring the first metatarsal head laterally back to its normal position over the sesamoids. This correction requires a metatarsal osteotomy, which can be done at different levels. Metatarsal osteotomies, although numerous, can be classified into 2 major groups: angulation and displacement. Of these, displacement osteotomies are usually done distally through the metaphysis, and the angulation osteotomies proximally and even including arthrodesis at the first tarsometatarsal joint (13,14). The Austin, or so-called chevron osteotomy (and its modifications), is a typical example of distal osteotomies that is widely accepted as the first choice in the treatment of hallux valgus because of its simplicity, initial stability, and postoperative comfort for the patient (15). Additionally, distal osteotomies have the ability to correct the distal metaphyseal articular angle (DMAA), whereas angulation osteotomies have an adverse effect on the DMAA, which may require an additional distal osteotomy to eliminate this problem. Displacement osteotomies produce a decrease in bony contact between the osteotomy fragments depending on the amount of correction. This displacement may present a risk for primary stability at the osteotomy site and union of the fragments.

Angulation osteotomies are done proximally and have the advantage of a robust correction without loss of bony contact between the fragments. However, proximal osteotomies are technically more demanding and prone to complications with some discomfort for the patients postoperatively, such non-weightbearing or casting owing to instability (16). Therefore, it would seem logical to choose a distal displacement osteotomy as a first choice in appropriate cases and defer a proximal osteotomy for more severe deformities. To make an appropriate preoperative decision, the question at this point should be, which cases are ideal for a displacement osteotomy? Classic knowledge addresses this issue with the intermetatarsal and HVAs and indicates a need for a more proximal osteotomy for more severe angular deformities. Following this concept of angular severity, Coughlin et al (2) and Robinson and Limbers (1) developed treatment algorithms, and 14° of IMA was accepted as the upper limit for displacement osteotomies. Instead of angular criteria, the estimated amount of bony contact between the fragments, after sliding the distal fragment laterally, would

seem to be a more logical and straightforward approach to us to determine the appropriate operation. We developed a new technique to address this issue and found it reliable and simple for decision making in the correction of hallux valgus.

Today, we are all aware of the importance of decreasing the IMA to obtain a satisfactory long-term result in this condition (17). Related to this knowledge, the most common component of hallux valgus surgery is a metatarsal osteotomy to bring the metatarsal head laterally to where it is supposed to be. Lateral shifting of the metatarsal head not only corrects the main pathology responsible for the deformity but also eliminates the patient's primary concern, the bump on the medial side of the great toe without a need to remove it. This can be done proximally by angulating the distal fragment, or distally by shifting it. Literature indicates that distal shifting has significant advantages over proximal tilting (18). Distal procedures are technically simple and more forgiving for the surgeon and have the benefit of correcting the DMAA. Fixation and union are better in this region, allowing the patient early ambulation. Therefore, distal displacement osteotomies seem to be the procedure of choice in hallux valgus surgery whenever indicated (19). All other extensive operations should be reserved for more severe cases in which a distal displacement osteotomy is thought to be inadequate for correction, with 1 exception, which is first ray instability. A foot surgeon, therefore, must be aware of the potential for correction of a distal shifting in hallux valgus. A foot surgeon must be aware of the potential power of a distal shifting osteotomy and its limitations to correct bunion deformities. We believe, as the cases presented here demonstrate, the power of distal osteotomies is underestimated.

Although the deformity is angular, shifting a bone fragment on another one is not a matter of angles and should not be measured by angular criteria but by the distances that limit it. We think the most important 2 factors limiting the amount of displacement are the width of the bone to be displaced, which is the diameter of the metatarsal head, and the distance to where it can be shifted maximally, which is the distance between the first and second metatarsal bones. Whether done proximally or distally, a metatarsal head can be displaced only as much as the distance between the first 2 metatarsals, and there is no need to perform this by a proximal osteotomy if this can be done distally unless a safe amount of contact between the fragments is going to be lost. As stated before, these parameters are not subject to the angles but directly to the metatarsal head diameter and the required amount of lateral displacement to make a proper decision. Two hallux valgus cases with the same amount of angular deformity may require different operations due to a difference in their metatarsal head diameters (Fig. 2). A safe amount of lateral displacement is beyond the scope of this article but needs to be investigated biomechanically. However, we felt secure to displace along plantar arm DCO or L type distal metatarsal



Fig. 2. Two cases with the same amount (intermetatarsal angle 21°) of angular deformity with different metatarsal head diameters. Expected bony contacts after correction were calculated as 33% and 71% for the left and right radiographs, respectively, indicating that angular measurement alone is not a reliable indicator for choosing the appropriate operation.

osteotomy up to 50% of the head diameter in our clinical practice. We have patients in whom we performed lateral displacement at >50%. However, avascular necrosis and lateral tilting of the distal fragment that leads increased DMAA are potential complications. Until further investigation, we are not able to recommend safe displacement beyond 50%. In recent years, we prefer to use a long plantar arm DCO, which provides more surface area and stability, and all patients in this study were operated using a long plantar arm osteotomy.

Classic knowledge indicates that the upper limit of distal osteotomies is 14°. If the normal IMA is <9°, maximum 4° to 6° of correction has been thought to be possible with this procedure. However, classic algorithms are based on the abovementioned angles and do not take the width of the bone into account. In our opinion, bone contact after a distal shifting osteotomy is the most crucial determinant of decision making for this type of surgery. Angle measurements are indirect, whereas absolute distances are direct determinants of this kind of procedure.

There are also some researchers supporting this view who found equal correction by DCO and Scarf osteotomies (3). A tendency toward massive corrections by distal displacement osteotomies exist in hallux valgus surgery (4,5); however, the indications are not clear.

We believe another reason that has limited the indication of distal metatarsal osteotomies to 14° of IMA has been the removal of the bony prominence. Some techniques have been defined in the literature to remove the excess bone as the first step of hallux valgus correction. However, Thordarson and Krewer (18) found that “hypertrophy of the medial eminence is not a component of the pathology.” They found that the thickness of the medial eminence is 4.1 and 4.3 mm in the control and hallux valgus groups, respectively, and the difference was not

statistically significant (18). Removal of any bone, even if it exists, in this region as the first step will eventually decrease the amount of lateral shifting by leaving less contact between the fragments. Therefore, if a need exists, it should be assessed at the end and should be done as the last step in the surgical treatment of hallux valgus in our opinion.

We preferred the lateral cortex of the fibular sesamoid as the reference to determine the minimum preoperative amount of lateral shifting distance that will allow us to achieve an acceptable sesamoid reduction. Previous studies showed that any change in the position of the sesamoid apparatus is a direct result of a change in position of the first metatarsal, which occurs as a result of the surgical procedure or procedures performed. The sesamoid apparatus itself does not move (20). This means that the lateral cortex of the fibular sesamoid is a reliable and stable anatomic landmark for preoperative planning the minimum amount of lateral shifting to reduce sesamoids. Our clinical experience is also consistent with this (Figs. 3 and 4). Also, hallux valgus may be accompanied by sesamoid subluxation and first metatarsal head pronation. We excluded patients with evident tarsometatarsal joint instability and or hypermobility. In these cases, a Lapidus procedure is preferable (21,22).

Early studies stated that lateral translation of the capital fragment should not exceed 30% of the metatarsal width because of the increase of avascular necrosis, delayed union, malunion, and dislocation of the capital fragment (7,23). These early studies did not use any fixation on osteotomy site; they only relied on the inherent stability of the osteotomy for maintenance of the correction that was obtained intraoperatively. Using fixation with K wire or as today with modern mini-compression screws, large displacements can be obtained without an increase in the rate of avascular necrosis (3–5).

Mavcic (24) created a geometric preoperative planning model based on subcapital metatarsal width, medial bunion eminence, and metatarsal length for minimally invasive distal metatarsal osteotomy. He concluded that minimally invasive distal metatarsal osteotomy cannot sufficiently correct all deformations within the boundaries of IMA angle <20° and HVA <40°. In patients with large eminences and narrow metatarsals, complications related to insufficient postoperative fragment contact can be expected, whereas sufficient hallux valgus correction in patients with small eminences and long metatarsals is questionable (24). When a surgeon prefers a non-chevron type transverse or oblique distal osteotomy, the metatarsal head tends to have an additional dorsal or plantar displacement. The surface of distal metatarsal fragments has a circular shape, and this dorsal or plantar displacement greatly reduces the contact surface and limits the use of distal transverse or oblique osteotomies. A chevron type osteotomy has a clear advantage of remaining contact surface after lateral shifting, thus is a suitable choice for large displacements in our opinion.

Sarrafiyan (6) created a method to predict the degree of functional correction with a distal lateral displacement osteotomy based on the metatarsal width and IMA measurements. This method uses multiple angular measurements and complicated calculations, making the measurements controversial by means of interobserver reliability. Also, this

Table 3
Surgical options advised according to angular classification

	Coughlin et al (2), 2007	Robinson and Limbers (1), 2005
Mild	Chevron, Mitchell, or proximal osteotomy*	Chevron osteotomy*
Moderate	Mitchell or proximal osteotomy*	Scarf osteotomy*
Severe	Proximal osteotomy, MTP fusion*	Scarf, proximal osteotomy, Lapidus procedure*
TMT instability	Lapidus procedure*	Lapidus procedure*
Congruent	Biplane chevron osteotomy	Scarf osteotomy

Abbreviation: MTP, metatarsophalangeal; TMT, tarsometatarsal.

* Incongruent hallux valgus combined with a distal soft-tissue procedure.

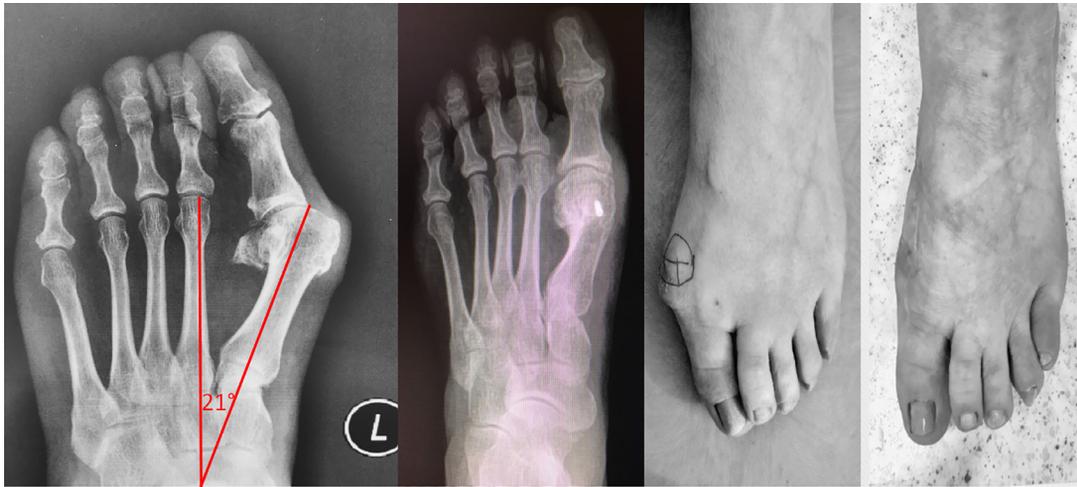


Fig. 3. A case with intermetatarsal angle 21° and hallux valgus angle 47° . Two years of postoperative radiograph shows adequate correction by a distal chevron osteotomy. Note the wide metatarsal head was allowing 71% bony contact after the displacement to correct the deformity and reduce sesamoids.

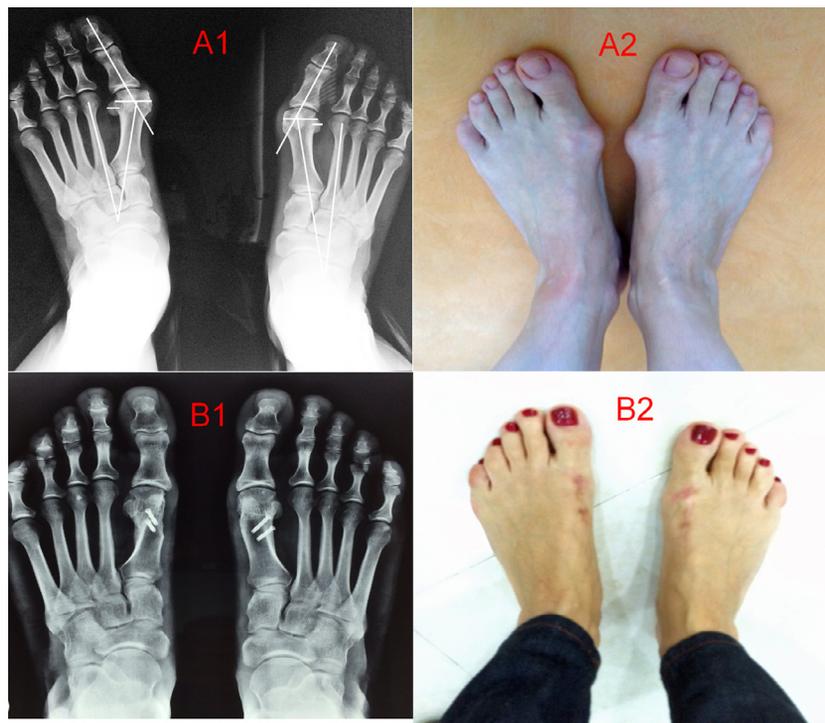


Fig. 4. (A1–A2) Another case with intermetatarsal angle 21° and hallux valgus angle 16° . Metatarsal head diameter is adequate and expected bony contact between the fragments is 83% and 85%, thus allowing a distal metatarsal displacement osteotomy. (B1–B2) Late postoperative radiograph (1 year) shows proper correction, sesamoid reduction, and healing.

method needs strict radiologic standards to make precise calculations (6). With our method, we use proportions of distances. The unit of distances (inch, cm, mm, etc.) is not important. Easy calculation of distances with clear anatomic landmarks nearby (lateral sesamoid and metatarsal head) could enhance the interobserver reliability.

Current treatment algorithms popularized by Robinson and Limbers (1) and Coughlin et al (2) are based on angular measurements. Also, first metatarsocuneiform joint hypermobility (tarsometatarsal) and congruency measured by the DMAA are other contributing factors affecting the choice of surgical procedure according to these algorithms. Tables 1 and 3 show these widely accepted treatment algorithms based on angular measurements of HVA and IMA.

Studies by Deenik et al (25) reported that the preoperative HVA was the main radiologic predictor for correction of hallux valgus, and IMA

and DMAA did have a minor role in patients with preoperative HVA <37 degrees. Also, they concluded that the presently used treatment algorithms for hallux valgus surgery are primarily based on expert opinion and are not supported by level 1 and 2 studies. The possible advantage of specific surgical procedures should be based on controlled clinical studies (26).

Our results showed mean contact percentage decrease as IMA increased. This result is consistent with traditional knowledge. However, we also observed that 2 patients with the same IMA can have a different contact surface varying on a broad spectrum (Fig. 2). This proves that IMA can be inconsistent to determine the stability of DCO. We calculated that a significant number of patients with larger distal metatarsal width have enough contact area to perform a DCO. Also, we presented a new alternative method to select suitable patients for DCO

based on the width of the metatarsal head, lateral shifting distance, and contact percentage after osteotomy.

We defined strict exclusion criteria to minimize the variables that can affect the surgical outcomes, such as congenital deformities of the foot; hallux rigidus; metatarsus adductus; tarsometatarsal joint instability and or hypermobility; previous first ray trauma or foot and ankle surgery; or diagnosis of rheumatic, dysmetabolic, neurologic, infective, or psychiatric pathologies. This limited the number of patients in our study to 24. A future study with a larger sample size would be statistically more valuable. Also, the reliability of the new measurement EBC needs to be investigated by means of interobserver and intraobserver reliability.

In conclusion, the IMA may not always be a reliable parameter to predict the stability of DCO. Because the primary aim of a distal metatarsal osteotomy is shifting and the stability depends on the contact surfaces of osteotomy fragments, metatarsal head diameter and remaining bone contact after lateral shifting should be the primary concerns for the surgeons. Two patients with the same IMA can have a different contact surface varying on a broad spectrum.

References

1. Robinson AH, Limbers JP. Modern concepts in the treatment of hallux valgus. *J Bone Joint Surg Br* 2005;87:1038–1045.
2. Coughlin MJ, Mann RA, Saltzman CL. *Mann's Surgery of the Foot and Ankle*. Mosby, Maryland Heights, MO, 2007;184–362.
3. Deenik A, van Mameren H, de Visser E, de Waal Malefijt M, Draijer F, de Bie R. Equivalent correction in scarf and chevron osteotomy in moderate and severe hallux valgus: a randomized controlled trial. *Foot Ankle Int* 2008;29:1209–1215.
4. Bai LB, Lee KB, Seo CY, Song EK, Yoon TR. Distal chevron osteotomy with distal soft tissue procedure for moderate to severe hallux valgus deformity. *Foot Ankle Int* 2010;31:683–688.
5. Stienstra JJ, Lee JA, Nakadate DT. Large displacement distal chevron osteotomy for the correction of hallux valgus deformity. *J Foot Ankle Surg* 2002;41:213–220.
6. Sarrafian SK. A method of predicting the degree of functional correction of the metatarsus primus varus with a distal lateral displacement osteotomy in hallux valgus. *Foot Ankle* 1985;5:322–326.
7. Harper MC. Correction of metatarsus primus varus with the Chevron metatarsal osteotomy: an analysis of corrective factors. *Chn Orthop Relat Res* 1989;243:180–183.
8. Badway TM, Dutkowsky JP, Graves SC, Richardson EG. An anatomical basis for the degree of displacement of the distal chevron osteotomy in the treatment of hallux valgus. *Foot Ankle* 1997;18:213–215.
9. Myerson MS, Kadakia AR. *Reconstructive Foot and Ankle Surgery: Management of Complications*. 3rd ed. Saunders, Philadelphia, 2018.
10. Kitaoka HB, Alexander IJ, Adelaar RS, Nunley JA, Myerson MS, Sanders M. Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. *Foot Ankle Int* 1994;15:349–353.
11. Ibrahim T, Beiri A, Azzabi M, Best AJ, Taylor GJ, Menon DK. Reliability and validity of the subjective component of the American Orthopaedic Foot and Ankle Society clinical rating scales. *J Foot Ankle Surg* 2007;46:65–74.
12. Shima H, Okuda R, Yasuda T, Jotoku T, Kitano N, Kinoshita M. Radiographic measurements in patients with hallux valgus before and after proximal crescentic osteotomy. *J Bone Joint Surg Am* 2009;91:1369–1376.
13. Morris J, Ryan M. First metatarsal base osteotomies for hallux abducto valgus deformities. *Clin Podiatr Med Surg* 2014;31:247–263.
14. Chandler LM. First metatarsal head osteotomies for the correction of hallux abducto valgus. *Clin Podiatr Med Surg* 2014;31:221–231.
15. Austin DW, Leventen E. A new osteotomy for hallux valgus: a horizontally directed "V" displacement osteotomy of the metatarsal head for hallux valgus and primus varus. *Clin Orthop* 1981;157:25–30.
16. Schuh R, Willegger M, Holinka J, Ristl R, Windhager R, Wanivenhaus AH. Angular correction and complications of proximal first metatarsal osteotomies for hallux valgus deformity. *Int Orthop* 2013;37:1771–1780.
17. Okuda R, Kinoshita M, Yasuda T, Jotoku T, Shima H. Proximal metatarsal osteotomy for hallux valgus: comparison of outcome for moderate and severe deformities. *Foot Ankle Int* 2008;29:664–670.
18. Thordarson DB, Krewer P. Medial eminence thickness with and without hallux valgus. *Foot Ankle Int* 2002;23:48–50.
19. Pinney S, Song K, Chou L. Surgical treatment of mild hallux valgus deformity: the state of practice among academic foot and ankle surgeons. *Foot Ankle Int* 2006;27:970–973.
20. Judge MS, LaPointe S, Yu GV, Shook JE, Taylor RP. The effect of hallux abducto valgus surgery on the sesamoid apparatus position. *J Am Podiatr Med Assoc* 1999;89:551–559.
21. Kim JS, Young KW. Sesamoid position in hallux valgus in relation to the coronal rotation of the first metatarsal. *Foot Ankle Clin* 2018;23:219–230.
22. Wagner P, Wagner E. Is the rotational deformity important in our decision-making process for correction of hallux valgus deformity? *Foot Ankle Clin* 2018;23:205–217.
23. Bonnel F, Canovas F, Poirée G, Dusserre F, Vergnes C. [Evaluation of the Scarf osteotomy in hallux valgus related to distal metatarsal articular angle: a prospective study of 79 operated cases]. *Rev Chir Orthop Reparatrice Appar Mot* 1999;85:381–386.
24. Mavcic B. Geometric analysis of indications for minimally invasive distal metatarsal osteotomy in treatment of hallux valgus. *J Orthop Surg Res* 2015;10:163.
25. Deenik AR, de Visser E, Louwerens JW, de Waal Malefijt M, Draijer FF, de Bie RA. Hallux valgus angle as main predictor for correction of hallux valgus. *BMC Musculoskelet Disord* 2008;9:70.
26. Deenik A, Verburg A, Louwerens JW, de Waal Malefijt M, de Bie R. Evidence of treatment algorithms for hallux valgus. *JSM Foot Ankle* 2016;1:1003.