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Percutaneous, Intra-articular, Chevron Osteotomy (PeICO) for the Treatment of Hallux Valgus: A Cadaveric Study

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Abstract

Background: Percutaneous surgery is experiencing sustained growth based on third-generation techniques. This cadaveric study was designed with the main goal of exploring the risk of iatrogenic tendon and neurovascular lesions and defining the safe zones in a percutaneous, intra-articular, chevron osteotomy (PeICO) procedure, as well as assessing the accuracy of the osteotomy itself.
Methods: Eight feet from below-knee fresh-frozen specimens were selected. After the procedure, the specimens were dissected, and structures were inspected for damage.
Results: The results of the safety measurements were as follows: (1) distance between portal 1 (P1) and the lateral border of the extensor hallucis longus (EHL) tendon: average 17.6 mm (range 12.7-21.3); (2) distance between P1 and the dorsomedial digital nerve (DMDN): average 7.2 mm (range 1.6-10.4); (3) distance between P1 and the metatarsophalangeal joint: average 15.7 mm (range 9.4-20.5); distance between portal 2 (P2), or the osteosynthesis portal, and the metatarsophalangeal joint: average 25.5 mm (range 22-30.4); distance between P2 and the lateral border of the EHL tendon: average 12.7 mm (range 8-16.7); and distance between P2 and the DMDN: average 4.1 mm (range 1.7-8.2). There were no iatrogenic injuries. The osteotomy angulation in the sagittal plane (reproducibility) average was 85.6 degrees.
Conclusion: There were no iatrogenic injuries on this cadaveric study of PeICO.
Clinical Relevance: This study will help orthopedic surgeons understand the risks of performing percutaneous surgery by mimicking an accepted open technique (chevron).

Keywords: hallux disorders, percutaneous, chevron, cadaveric study

Minimally invasive surgery (MIS), also known as percutaneous surgery, has experienced a sustained growth for the treatment of foot and ankle problems, especially over the last decade. This is supported by numerous studies including clinical series,[3,5,6,8,11,15,18,20,28,33] comparative studies,[7,22,23,38] technical reports[27,41] and radiologic validations.[17]

Recently, 3 systematic reviews concluded that MIS is safe and reliable for hallux valgus surgery.[4,9,31] Four cadaveric studies deemed percutaneous forefoot surgery a safe technique when it is performed by experienced surgeons,[13,21,43,48] which agrees with clinical studies.

Forefoot MIS is experiencing sustained growth based on third-generation (TG) techniques. Although the first[2,19] and second[6,32] generations continue to maintain their validity and indications, they are gradually making room for the emergence of new techniques. Specifically,

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Table 1. Demographic Data.

Age, y, mean ± SD	38 ± 15.9
Sex, n (%)	
Female	5 (62.5)
Male	3 (37.5)
Side, n (%)	
Left	6 (75)
Right	2 (25)
Hallux valgus	
Mild	3 (37.5)
Moderate	5 (62.5)

TG surgeries[8,23,25,40,46] involve procedures based on the design of open chevron osteotomies and can be divided into intra- and extra-articular procedures.

Percutaneous intra-articular chevron osteotomy (PeICO) for the treatment of hallux valgus was recently described and showed good potential for correction.[12] To date, no anatomical studies validating this technique are available, despite the technique being commonly used in the clinical setting. For this reason, this cadaveric study was designed with the main goal of exploring the risk of iatrogenic tendon and neurovascular lesions and defining the safe zones in a PeICO procedure, as well as assessing the accuracy of the osteotomy itself.

Materials and Methods

Eight feet (4 right and 4 left) from below-knee fresh-frozen specimens were selected. The cadavers included 3 men and 5 women with an average age of 38 (SD 15, 9), who contributed a total of 6 left and 2 right feet. Three and 5 specimens had a mild or moderate hallux valgus deformity, respectively. Ethical approval was obtained from our institutional review board. The demographic data is shown in Table 1. Specimens were not selected if there was evidence of ulcers, deformities, or operative incisions from previous foot and/or ankle procedures.

One surgeon performed all the procedures. The surgeon was specialized in foot and ankle surgery with more than 10 years of experience in percutaneous procedures. In each foot, a PeICO was performed on the first ray and an adductor tenotomy and lateral release (latero-plantar capsule) of the first MTP joint (first web space portal). After completing the surgical procedure, all specimens were dissected by an experienced anatomist.

To evaluate the safety of the procedure, the following data were obtained:

1. Distance between P1 and the lateral border of the EHL tendon
2. Distance between P1 and the dorsomedial digital nerve (DMDN)
3. Distance between P1 and the metatarsophalangeal joint
4. Distance between P2, or the osteosynthesis portal, and the metatarsophalangeal joint
5. Distance between P2 and the lateral border of EHL tendon
6. Distance between P2 and the DMDN

This anatomical study also assessed whether there was any arterial plexus damage present by the examination of the integrity of the soft tissue and the MTP capsule around the first metatarsal. In addition, the detachment of the dorsal capsule was evaluated.

In addition, the following measurements were taken: angulation of the osteotomy in the sagittal plane (reproducibility of a single surgeon) and the intermetatarsal and hallux valgus angles (correction power).

The dorsomedial digital nerve (DMDN) and the dorsolateral digital nerve (DLDN) of the hallux and its branches were recognized after creating a window of approximately 9 × 6 cm in the skin.

Two independent observers (one foot and ankle fellow and the other a 4-year-experience foot and ankle surgeon) made all the assessments and each one made 2 measurements of each parameter.

The following equipment was required:

- Burrs: Isham straight flute Shannon (ISFS) and wedge burr 3.1
- Instruments: Regular mini blade No. 6400, Freer elevator, bone rasp (small)
- Mini C-arm (preferable) or C-arm
- 2-mm K-wire
- 3.0-mm conical cannulated screw

The technique can be divided into the following steps:

1. A 2.0 mm × 20 cm K-wire was placed into the medial subcutaneous tissues of the hallux. It was advanced until it stopped at the medial surface of the first MTP joint.
2. A 3-mm medial portal (P1) was made with an MIS surgical blade at the limit between the proximal third and the distal two-thirds of the first metatarsal (1MT) head, using the C-arm to confirm the correct position.
3. A percutaneous dorsal capsular detachment was then performed to allow cephalic mobilization, similar to the open chevron (Figure 1). The burr (Isham straight flute Shannon) was inserted with a medial-to-lateral course through the 1MT head to create the apex of PeICO (Figure 2).

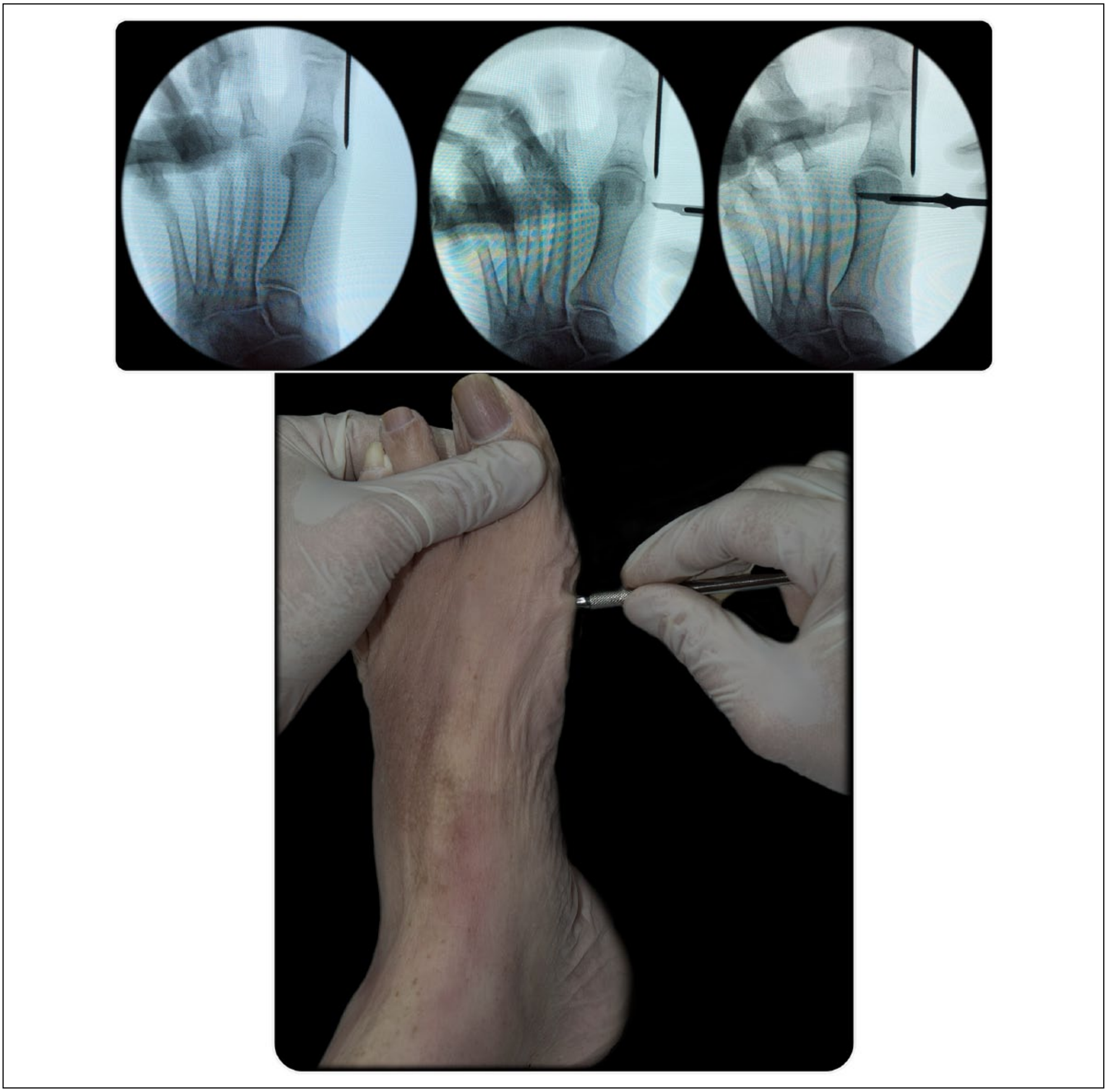

Figure 1. A percutaneous dorsal capsular detachment is then performed to allow cephalic mobilization, similar to the open chevron.

4. Then, the dorsal limb of the PeICO was made perpendicular to the 1MT diaphysis creating a 10- to 20-degree angle from the apex point. Great care was required to avoid damage to the DMDN. The horizontal portion of the osteotomy was performed from the apex point in a proximal direction parallel to the floor. The angle created by the 2 limbs was between 80 and 100 degrees.
5. The lateral shift of the 1MT (up to 50%) was carried out with a 2-mm Kirschner-wire and an angled stem probe ("Bosch method" 7). The probe was inserted through P1 and not through an accessory portal as described for other procedures. Then, the K-wire was advanced with the aid of a mallet while the surgeon applied an external rotational maneuver force to displace the head, and the K-wire was subsequently removed.
6. Then, through a dorsomedial portal (P2 ≅ 15 mm proximal and 3 mm dorsal to P1), a guidewire was placed to fix the osteotomy. The stabilization was

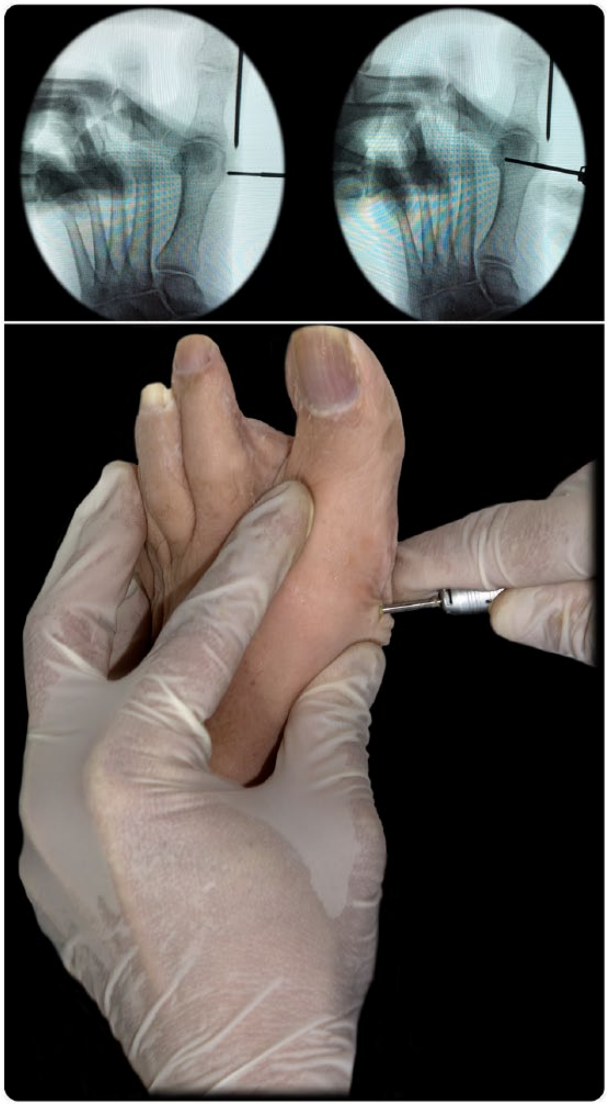

Figure 2. Perpendicular introduction of the burr and execution of the dorsal arm of PeICO. (PeICO, percutaneous, intraarticular, chevron osteotomy.)

preferably performed with a 3.0-mm headless screw from a dorsal-medial to lateral-plantar direction at a 45-degree angulation on the anteroposterior view (Figure 3). After the guidewire was removed, the resection of the remaining bunion was performed through the P2 with a 3.1 wedge burr.

7. Percutaneous adductor tenotomy and lateral release was not made before performing the PeICO, as it could have caused a loss of control of the 1MT head. This step involved the tenotomy of the adductor hallucis tendon and the release of the latero-plantar capsule. This was completed using an MIS blade that was introduced into the first web space through an accessory portal (P3). To section the sesamoid phalangeal ligament, the blade was rotated toward the first web space while the hallux was forced into varus. Final anteroposterior and lateral radiographs are shown in Figure 4.

Statistical Analysis

Statistical graphics and summary measures, including the mean, median, and standard deviation, were used to describe the data. Linear mixed effects models were conducted to control for observer and individual influences. To assess the significance of the model coefficients, probability ratio tests were conducted. Statistical analysis was performed using R language version 3.4.3. A *P* value of less than .05 was considered to be statistically significant.

Results

The measurements obtained in the anatomical study are displayed in Table 2 as a summary of the anatomical structures facing possible damage following percutaneous hallux valgus treatment using the PeICO technique. There were no iatrogenic injuries. Nevertheless, the distance between the osteosynthesis portal and DMDN showed the lowest average distance (Figures 5 and 6).

With respect to the osteotomy angulation in the sagittal plane (reproducibility), the average angulation was 85.6 degrees (range: 81-95 degrees) (Figure 7). The mean preoperative intermetatarsal angle (IMA) was 9.8 degrees (range: 8-18 degrees), and postoperatively, the mean IMA was 8 degrees (range: 4-13 degrees). Before surgery, the mean hallux valgus angle (HVA) was 22 degrees (range: 13-40 degrees), and the average postoperative HVA was 13.5 degrees (range: 6-34 degrees).

Discussion

The most important finding of this study was that PeICO was a safe procedure and that, in trained hands, results could be reliably reproduced. In addition, measurements obtained provide the surgeon with the information about the structures at risk during the procedure, mainly, the distance between the osteosynthesis portal and DMDN. In a previous publication, we reported the radiologic outcomes of PeICO in 21 patients (24 feet).[12] All patients were diagnosed with moderate hallux valgus, and the mean follow-up was 11.6 months (6-18, SD 4,67). The mean preoperative IMA between M1 and M2 was 12.5 degrees (range: 11-15 degrees, SD 1.03). Postoperatively, the IMA was 8.1 degrees (range: 5-10 degrees; SD 1.16), with an average angular correction of 4.3 degrees. The mean HVA was 34.0 degrees (20-40 degrees; SD 4.93) before surgery, and the average

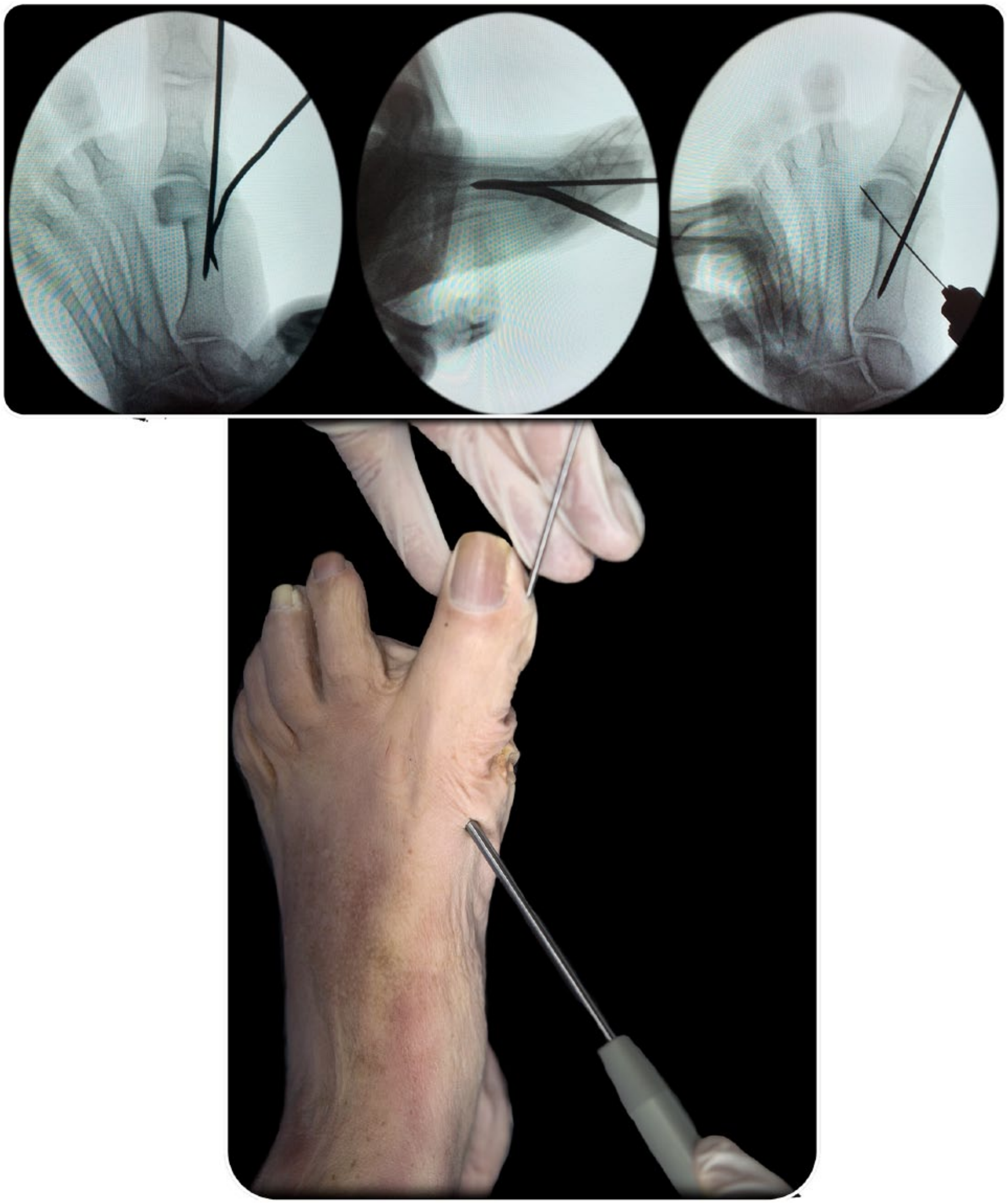

Figure 3. Stabilization of PeICO. (PeICO, percutaneous, intraarticular, chevron osteotomy.)

postoperative HVA was 8.2 degrees (range: 3-15 degrees, SD 2.86), thus obtaining an average overall improvement of 25.9 degrees. No metatarsal shortening or recurrence was observed. The authors concluded that PeICO was effective for the treatment of hallux valgus with midterm satisfactory angular correction. These results agree with the present study. The overall complication rate in percutaneous surgery continues to be high, ranging from 6.9% to 29.4%.[3,4,7,18,31,38] This especially is a concern when these procedures are performed by unexperienced surgeons.[21,44]

The DMDN and dorsomedial digital nerve (DLDN)[13,48] are at risk during percutaneous forefoot surgery. Although nerve injury may not produce representative symptoms, neuroma generation may have a higher impact on patient satisfaction and may require revision procedures. Nerve injury rates of 2% to 15% have been reported.[29,43] This study showed no DLDN or DMDN lesions. Nevertheless, the distance between P2 (portal for osteosynthesis) and the DMDN showed the lowest average distance, 4.1 mm. Recently, in a cadaveric study that was divided into 2 surgical groups (experienced

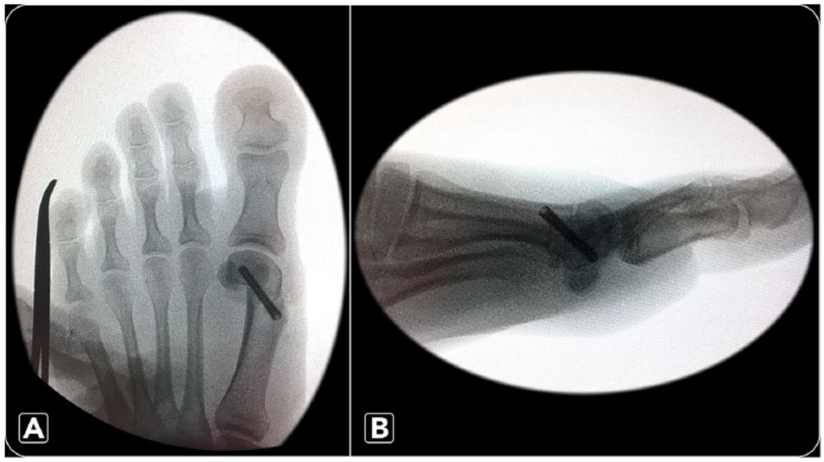

Figure 4. (A) Final anteroposterior and (B) lateral final radiograph.

Table 2. Distances From Portals to Anatomical Structures.

Parameters	Mean distance (mm)	Range (mm)	Deviation
Distance between P1 and lateral border of EHL	17.6	12.7-21.3	2.4
Distance between P1 and DMDN	7.3	1.6-10.4	2.5
Distance between P1 and MTPJ	15.7	9.4-20.5	3.0
Distance between P2 and MTPJ	25.6	22-30.4	2.2
Distance between P2 and lateral border of EHL	12.8	8-16.7	2.4
Distance between P2 and DMDN	4.2	1.7-8.2	2.0

Abbreviations: DMDN, dorsomedial digital nerve; EHL, extensor hallucis longus; MTPJ, metatarsophalangeal joint; P1, portal for percutaneous, intraarticular, chevron osteotomy; P2, portal for osteosynthesis.

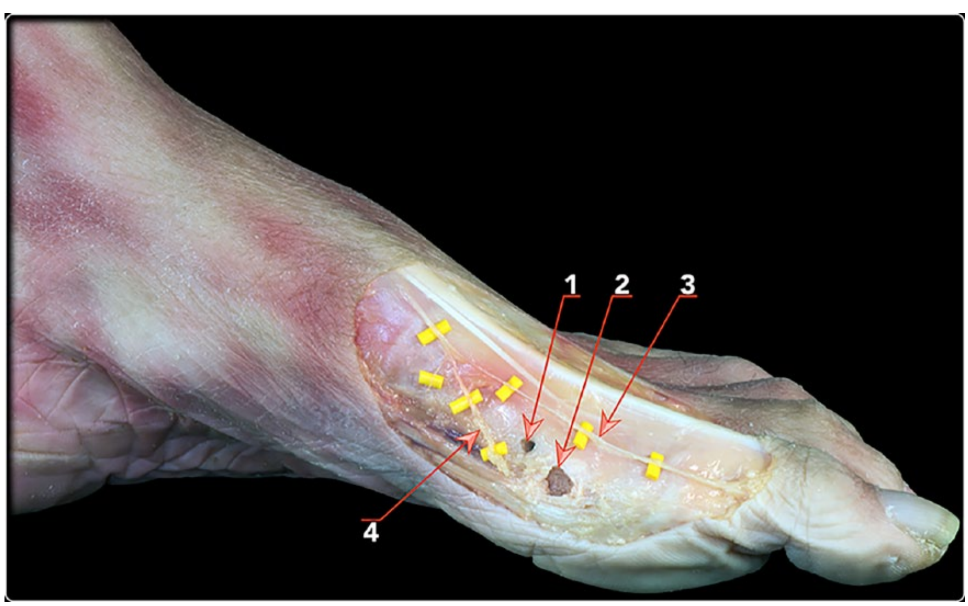

Figure 5. Medial view of a dissection of the first metatarsophalangeal joint after a PeICO was performed, demonstrating absence of lesion and integrity of the digital nerves. (1) Osteosynthesis portal; (2) osteotomy portal; (3) dorsomedial nerve of the first toe; (4) medial branch of the dorsomedial nerve of the first toe. (PeICO, percutaneous, intraarticular, chevron osteotomy.)

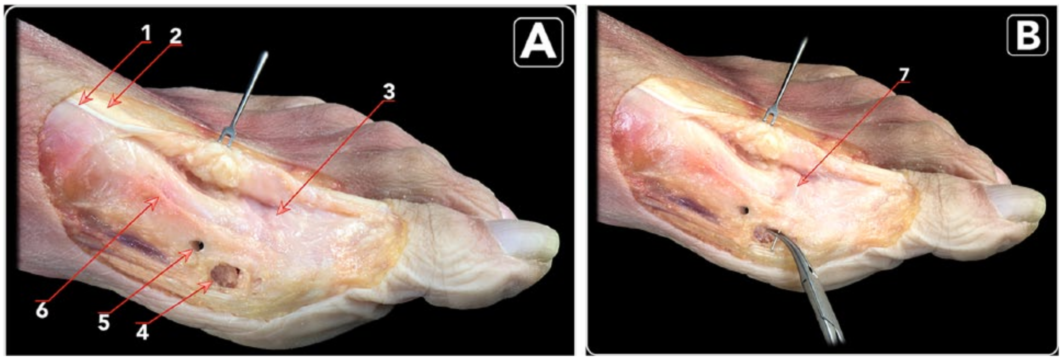

Figure 6. Dissection of the first metatarsophalangeal joint after a PeICO was performed. (A) View after osteotomy showing integrity of the dorsal capsule. (B) A mosquito needle is inserted to elevate the dorsal capsule and demonstrate the osteotomy is intra-articular. (1) Extensor hallucis capsularis; (2) extensor hallucis longus; (3) dorsal capsule of the first metatarsophalangeal joint; (4) osteotomy portal; (5) osteosynthesis portal; (6) dorsomedial nerve of the first toe; and (7) distended dorsal capsule of the first metatarsophalangeal joint.

Figure 7. Dissection of the metatarsal head after a PeICO was performed. Angulation of the chevron osteotomy can be observed both with the metatarsal head in position and also after its removal (upper right of the picture). (PeICO, portal for percutaneous, intraarticular, chevron osteotomy.)

surgeons and untrained residents at 10% to 40%, respectively), Kaipel et al[21] found a 20% instance of traumatic nerve lesions when performing a percutaneous Bosch osteotomy; this seems to be considerably higher than that of open surgeries and PeICO. However, the authors did not relate this complication to the location of the K-wire. To avoid injuries, the recently described clock method may be applied.[30] This method accurately describes the position of the DLDN and DMDN, which were described frequently as being located between 10 and 2 o'clock. This system represents a useful instrument in percutaneous surgery. Furthermore, the dorsal partial capsular detachment described did not injure either the DLDN or the DMDN.

The crucial blood supply to the first metatarsal head enters through a plexus located at the plantar side of the first MT neck just proximal to the capsular insertion.[39] This blood supply could be injured while performing a chevron technique and could produce avascular necrosis (AVN) of the first MT head. AVN is the most serious complication following a chevron osteotomy, with a reported incidence of 4% to 20%.[16] In 1994, Donnelly et al modified the orientation of the dorsal limb to create a 90-degree angle to minimize the risk of AVN. Clinical and anatomical studies recommend performing the osteotomy with a long plantar arm exiting proximal to the capsular attachment.[14] Dhukaram et al found no injury of the capsule and soft tissue sleeve around the first MT head and, therefore, concluded that no injury was caused.[13,14,42] In addition, although a greater correction can be achieved with a more extensive lateral release, this can increase the risk of AVN up to 40%. However, in other studies, no such complication has been found.[36,40] In PeICO, a lateral release through an MIS portal was performed, only sectioning the abductor tendon and a small portion of the capsule (latero-plantar), thus avoiding any vascular injury that could lead to complications.

Tendon injuries ranging from 0% to 5% have been described after foot percutaneous surgical techniques.[34,43] Dhukaram et al[13] showed no tendon injuries in their study, including when using the MICA technique. Nevertheless, tendon lesions seem more frequent if an Akin osteotomy is performed.[48] No tendon lesions were found in this study; however, the tendons are at higher risk of being injured if they are in tension against the burr. The EHL is especially at risk while performing the dorsal portion of the PeICO. To minimize the risk, maintaining the joint in 20 to 30 degrees of dorsiflexion is recommended to reduce the tension of the tendon while performing the osteotomy.

Angulation of the osteotomy after PeICO was found to be in the correct plane. As shown in the results, the average angulation of the osteotomy was 85.6 degrees, whereas 90 degrees is recommended in published studies.[14,47] This difference may be attributable to the fact that percutaneous surgery is performed without direct visualization of the bone. Nevertheless, the angulation is close enough to 90 degrees to prove the effectiveness of the technique, although it has to be considered that it was performed by a surgeon experienced in open and MIS foot and ankle procedures.

Stable fixation is imperative in preserving the position of the PeICO. There is no need to cross the lateral cortex of the distal metaphysis and/or to use 2 screws to provide secure angular stability, as other techniques require.[23,40,41] Some procedures use 1 screw and an intramedullary K-wire to achieve stability.[8] The technique described here only needs 1 screw, similar to open surgery procedures.

Adductor tenotomy and lateroplantar capsulotomy was performed by positioning the blade at the level of the joint under image intensifier control. Although some MIS procedures do not appear to need lateral release,[4,15,24,26] others only perform the adductor tenotomy and a partial lateral capsule release.[11,34] The precise indications for those who can benefit from this procedure remain a matter of discussion.[7,25] In addition, it should be defined which patients need an adductor tendon release and which ones require an extended lateral release.

Considering the indications and potential advantages of percutaneous surgery, some authors have experimented with osteotomies similar to the open chevron, although with conceptual differences. They can be divided into intra- or extra-articular osteotomies. Some examples of those performed proximal to the joint capsule (extracapsular) are as follows. A MICA (minimally invasive chevron Akin) is performed at the neck of the first metatarsal (extra-articular) and requires 2 screws for the stabilization of the osteotomy associated with an Akin osteotomy.[20,41,46] It has shown good to excellent results. According to the authors, the development of this fixation (MICA) allows it to be used in severe hallux valgus. This osteotomy can be laterally displaced up to 100% and offers a valid technique for all degrees of hallux valgus. A PECA (percutaneous chevron/Akin), which is technically identical to MICA, has shown comparable outcomes to the new technique (equated to open scarf/Akin).[23] An MIS chevron recently described by Brogan et al needs 1 screw and K-wire to provide stability.[7,8] In a comparative study, no differences in complications were found between the MIS chevron and open chevron, thereby showing that both are safe procedures with good clinical outcomes for symptomatic, mild-to-moderate hallux valgus. A PERC (percutaneous extra-articular reverse-L chevron osteotomy) is also performed on the metaphysis of the first metatarsal (1MT),[25] and the main difference between PERC and other techniques is that the osteotomy is stabilized with a dorsal-to-plantar screw. According to the authors, this technique is reliable, reproducible, and maintains an excellent range of articular motion. The theoretical advantages of the PeICO technique compared to the other third-generation techniques are that it has greater intrinsic stability due to greater bone contact surface, it only needs 1 screw for its stabilization, which, consequently, leads to a shorter operative time, and it is associated with fewer complications. The PeICO technique reliably imitates the open chevron procedure, and it is expected to reproduce all its known virtues (reproducibility in trained hands, intrinsic stability, satisfactory clinical experience, etc). In addition, the PeICO procedure is designed not to create complications, such as AVN,[37,38] recurrence and reoperation,[35,36,45,46] second metatarsal transfer lesions,[1] and radiologic hallux varus.[10]

Some limitations exist in our study. The presented technique showed no macroscopic lesions. However, this study is a cadaveric evaluation and, thus, cannot show possible complications with clinical repercussions (infection, avascular necrosis, neuritis, hallux valgus recurrence, etc). The freezing process of the specimens may create changes in tissue volume. In addition, studies assessing clinical outcomes and complications of this novel technique are needed. Finally, this study was performed by a surgeon expert in foot MIS, and attention should be paid to the learning curve before trying to reproduce our results.

Conclusion

PeICO was a safe and reproducible technique for a surgeon already trained in foot MIS and who had completed the learning curve in percutaneous hallux valgus surgery. We believe it offers advantages over other techniques that have been described, because it does not need fixation with 2 screws, which results in a shorter surgical time with fewer steps, lower complication rate, and possibly decreased cost. Clinical data are needed to further validate the technique. We emphasize that percutaneous hallux valgus surgery has an extensive learning curve and, therefore, it may be difficult to reproduce the results shown in published data.

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