Short-Term Outcomes of Percutaneous, Intra-articular, Chevron Osteotomy (PeICO) for the Treatment of Mild to Moderate Hallux Valgus

Abstract

Background: Treatment for hallux valgus (HV) remains challenging. Third-generation percutaneous procedures try to reproduce chevron-type osteotomies to replicate their benefits, such as intrinsic stability and reproducibility. We report the first results using a Percutaneous, Intra-articular, Chevron Osteotomy (PeICO) technique that mimics the classic intra-articular open Chevron procedure, associated with a Percutaneous Adductor Tendon Release (PATR) for the treatment of mild-to-moderate HV.

Methods: From May 2015 to October 2018, a total of consecutive 114 feet (74 patients) were included. Primary outcome measures included: radiographic (hallux valgus and intermetatarsal angles) and clinical parameters such as visual analog scale (VAS), FAAM Activities of Daily Living (ADL) and FAAM Sport, AOFAS Score, and MOXFQ, preoperatively and at final follow-up (Minimum 18 months). A patient satisfaction survey was also performed. Pronation and length of the first metatarsal were also assessed. Secondary outcomes included fluoroscopic time, length of surgery, complications, recurrence and reoperation rates.

Results: At 24.09 months on average, the AOFAS score improved from 52.1 points preoperatively to 91.1 (p <0.001) at the latest follow-up. VAS decreased from 6.3 to 1. Also, FAAM ALD, FAAM Sport and MOXFQ showed statistically significant differences (p <0.001) when comparing preoperative and postoperative periods. Patients found the procedure to be excellent in 82% and very good in 13.5% of cases. Our global complication and reoperation rates were 5.26% and 3.5% (screw removal), respectively.

Conclusion: PeICO combined with PATR proved to be a safe, reliable and effective technique for the correction of mild-to-moderate HV deformity.

Level of Evidence: Level IV- Case Series

Keywords: Hallux valgus, percutaneous, chevron, outcomes

Introduction

Treatment for hallux valgus (HV) remains challenging. It continues to have a high patient dissatisfaction rate (10.6%), and postoperative first metatarsophalangeal (MTP) pain remains at 1.5% Barg A, which means that the search for a better procedure must continue. Osteotomies -especially chevron type- continue to be the method of choice to achieve correction of HV deformities. Klugarova J Matar HE

In order to improve the outcomes, percutaneous surgery (PS) or MIS ("Minimally invasive surgery") has been involved in a process of continuous change. Del Vecchio JJ, Ghioldi ME This does not necessarily mean an evolution, but rather a better understanding of the benefits and complications of previous generations. Third-generation or 3G Jowett CRJ Lai MC Liszka H Vernois J procedures reproduce chevron-type osteotomies to replicate their benefits, such as intrinsic stability and reproducibility. They are divided into extra-articular and intra-articular osteotomies.

Recently, comparative studies have shown similar radiological and clinical outcomes when comparing 3G techniques with open techniques for HV treatment. Brogan K Garcés JB Kaufmann G, Mörtlbauer L Lai MC Lee M Yassin M However, there is currently insufficient evidence to recommend PS over open procedures or to recommend one percutaneous approach over another for HV treatment. Jeyaseelan L Malagelada F

We report a prospective case series using a Percutaneous, Intra-articular, Chevron Osteotomy (PeICO) technique for the treatment of mild-to-moderate HV associated with a Percutaneous adductor tendon release (PATR). Dalmau-Pastor M, Malagelada F Del Vecchio JJ, Dalmau-Pastor M PeICO technique is the first published PS technique mimicking the classic intra-articular open Chevron procedure, and it has already shown excellent radiological correction Del Vecchio JJ, Ghioldi ME, Raimondi N and a cadaveric study showed that it is a safe and reliable procedure. Del Vecchio JJ, Ghioldi ME, Uzair AE, Chemes LN, Manzanares-Céspedes Recently, Del Vecchio et al. published a technical description associated with a case series. Del Vecchio JJ, Ghioldi ME, Uzair AE, Chemes LN, Dealbera ED. The question this study aims to answer is whether this new technique works properly when applied to patients.

Methods

From May 2015 to October 2018, a total of 177 consecutive patients underwent surgical treatment of unilateral/bilateral, painful, mild-to-moderate HV after failure of conservative treatment.

Exclusion criteria for this study included: stiffness of first MTP joint described as less than 75º of total range of motion (ROM) measured by placing a lateral goniometer, osteoarthritis of the MTP-1-joint (grade 1-3) Coughlin MJ, Shurnas PS, rheumatoid arthritis, patients with diabetes, neurological disorders, hypermobility of the first tarsometatarsal joint, and previous surgery on the same foot. Inclusion flowchart is shown in Figure 1.

After patient exclusion, 114 feet of 74 patients were included. The drop-out rate (lost to follow-up) was 30.8%. A 12-year-experienced MIS surgeon (JJDV) performed all the

PeICO procedures in association with PATR. All the patients underwent the same postoperative protocol.

The following data were assessed based on the patients' medical histories: general demographics (age, sex, and body mass index [BMI]), surgical details (such as length of surgery and fluoroscopy used), minutes of radiation exposure, associated procedures and complications.

Primary Outcome Measures

A radiographic evaluation was performed on standard foot anteroposterior (AP) and lateral weight-bearing images, preoperatively and at final follow-up (Minimum 18 months). Coughlin MJ, Saltzman CL These were made with the patient standing on both feet with the knees in full extension and included pre- and postoperative assessment of hallux valgus angle (HVA), intermetatarsal angle (IMA) and distal metatarsal articular angle (DMAA). Angles were measured following the AOFAS ad hoc Committee on Angular Measurements guidelines. Coughlin MJ, Saltzman CL Severity of hallux valgus was classified according to the HVA (≤15º, normal; less than 20º, mild; less than 40º, moderate; equal to or more than 40degrees, severe), and the IMA (<9º, normal; 9-11º, mild; 12-17º, moderate; ≥18º, severe).The tibial sesamoid position (TSP) was assessed: a line was drawn along the first metatarsal's longitudinal axis on the weight-bearing AP radiograph, and the position was classified as grade I-to-VII. Hardy RH First metatarsal length and postoperative shortening were also assessed.

Patients were also evaluated by measuring the range of motion (ROM) of the first MTP joint, preoperatively and at final follow-up (Minimum 18 months). ROM was classified as: normal (≥75º); moderate stiffness (30-74º); severe stiffness (<30º) or extension (<30º). Frigg A This was done with feet in a relaxed position of 30º of plantarflexion. Preoperatively, a goniometer was used to measure the ROM. The device was placed parallel to the first metatarsal dorsal aspect, with the other side being parallel to the dorsal aspect of the proximal phalanx. In the postoperative period, two radiographs were then taken whilst the patient's first toe was passively forced into maximum plantarflexion and dorsiflexion. ROM of the first MTP joint was measured twice in all patients by two different authors using the same method (mean values were calculated). Ozkurt B

The first metatarsal head pronation was also assessed using a modification of Yamaguchi's method Yamaguchi S (0-to-30º), based on a weight-bearing AP view. Recurrence was defined as an HVA of more than 15º at final follow-up. Raikin SM The length of the first metatarsal was also measured.

Clinical outcomes were assessed using the visual analog scale (VAS), FAAM ADL and FAAM Sport Sutton RM, AOFAS Score, and MOXFQ Garcés JB, preoperatively and at final follow-up (Minimum 18 months). A patient satisfaction survey was also performed, asking patients to assess their scale of satisfaction (Scores from 1 to 5: 1, unsatisfactory; 2, satisfactory; 3, good; 4, very good; 5, excellent) and whether they would go through the same technique again (question 2: yes/no). All patients were invited to complete the FAAM ADL, FAAM Sport, MOXFQ, VAS, and satisfaction scales by email.

Secondary Outcome Measures

Fluoroscopic time and length of surgery were recorded. Complications were identified by either the patient or the surgeon in outpatient clinics. We used a modification of the reliable Adapted Clavien-Dindo-Sink classification Sink EL for HV surgery and that already assessed a 3G procedure Lewis TL (Table 2). We categorized all complications following a retrospective case review. Complication data were routinely collected for all patients until discharge (follow up not less than 12 months) and, beyond this, complication data were identified only if the patient reported it. The reoperation rate and screw removal were also assessed.

Operative Technique

a) Patient positioning

With the patient supine with the foot overhanging about 5 cm beyond the operating table edge, and the surgeon seated facing the medial aspect of the foot.

b) Anesthesia

All procedures were performed under local anesthesia (Mayo block) with 5 mL of bupivacaine hydrochloride 0.5% w/v and 5 mL of xylocaine solution 0.5% associated with sedation. Intravenous antibiotics were administered as per local guidelines. We used a tourniquet, although it is important to use a high-torque and low-speed environment.

c) Equipment

The following equipment is required:

- Burrs: 2.0 × 12–mm Isham Straight Flute Shannon (ISFS) and Wedge Burr 3.1.
- Driver: Device with torque and speed control.
- One conical 3.5 mm screw.
- Instruments: Regular Mini Blade #6400, Freer elevator, bone rasp (Small).
- 2 mm x 20 mm K-wire.

The technique can be divided into five steps:

1. A 2.0 mm K-wire was slid percutaneously in the medial surface of the first toe in a distal-to-proximal orientation. A medial portal (P1) was made with a percutaneous surgical blade (SM69, Swann-Morton®) in the limit between the proximal 1/3 and the distal 2/3 of the 1MT head (Figure2).
2. A percutaneous dorsal capsular release was made to allow the first metatarsal head to move laterally. The hallux must be passive dorsiflexed (30º) to prevent soft tissue lesions (Figure 3). Then, the ISFS was inserted in a medial-to-lateral direction (until the lateral cortex) through the 1MT head to create the apex of the osteotomy. The dorsal limb describes a 20º angle proximally oriented whilst the plantar limb is parallel to the floor. This creates two limbs forming the 90º angle of a Chevron osteotomy (Figure 4). At this point, medial wedges (Triplanar PeICO) can be added to correct pronation (plantar limb) and DMMA (dorsal limb).
3. First metatarsal displacement. The lateral shift (up to 60%) was performed through a 2 mm K-wire and an angled stem probe. The probe was inserted through the osteotomy and the K-wire was advanced until proper correction was achieved (Figure 5).
4. A dorsomedial portal (P2: ≈15 mm proximal and 3 mm dorsal than the P1) was made for osteotomy stabilization. We prefer to use a 3.5 mm cannulated conical screw inserted from dorsal-medial to a lateral-plantar direction at a 45-degree orientation (Figure 6). After the 2 mm K-wire was removed, a resection of the medial eminence was made through portal 2 using a wedge Burr 3.1 (Figure 7).

5. PATR (Percutaneous adductor tendon release) was performed in association with all PeICO procedures, following published descriptions (Figure 8). Del Vecchio JJ, Dalmau-Pastor M Del Vecchio JJ, Dalmau-Pastor M
6. Through a medial portal, a percutaneous Akin was added in cases of persistent valgus of the great toe, using a weight-bearing intraoperative test.

Postoperative protocol

After achieving the required correction, a dressing was applied. The bandage circled the hallux, which was positioned in a slight varus. Immediate weight-bearing with a shoe with a flat, stiff sole was allowed as soon as the pain was tolerable. Ten to fourteen days postoperatively the stitches were removed, and the patient was trained to put daily bandages with hallux varus (5-to-10º) for the next four weeks. Four weeks after surgery, patients were advised to move their toe actively and passively. At six weeks postoperatively, rehabilitation was indicated if the ROM had decreased by more than 30º compared with the preoperative range.

Statistical Analysis

All statistical analyses were performed using R version 4.0.2. Descriptive statistics of position and scale were used for the continuous variables considered in two instances, before and after surgery. Scatter diagrams and boxplots were plotted to visualize their distribution. The difference variables between the records of each posterior and anterior patient were constructed and their normality was analyzed using the Shapiro-Wilks test. To assess whether the differences are statistically significant, the Wilcoxon test for paired samples was performed. Statistical significance was defined as a *p*-value of ≤0.05.

Results

The mean age was 45 years (range, 20-75; SD 14), with 69 female and five male patients. The mean follow-up was 24.08 months (range, 18-49; SD 8.53). The mean BMI was 27 ± 4.3 kg/m2. The procedures additional to PeICO were: one patient (1.35%) needed a DMMO (Distal metatarsal minimally invasive osteotomy) of second-to-fourth metatarsals for the treatment of central metatarsalgia; five, sliding-DMMO for the treatment of Tailor's bunion; three, percutaneous osteotomies of the proximal phalanx for lesser toes deformities (2-to-4 toes); and four, Akin osteotomies for the proximal phalanx of the first toe because of residual phalanx malalignment.

Primary Outcome Measures

The mean IMA improved from 12.51 ± 1.49º preoperatively to 7.89 ± 0.61º postoperatively (p <0.001), while the average HVA improved from 28.3 ± 5.08º preoperatively to 11.13 ± 3.74º postoperatively (p <0.001). We found 60.6% (69 feet) with mild and 39.4% (45 feet) with moderate HV deformity. There was an average of 1.94º (3.63º preoperatively to 1.69º postoperatively, p <0.001) of TSP improvement after the PeICO procedure (Figure 9). The average first metatarsal length was 60.9 mm in the preoperative and 58.6 mm in the postoperative period. This represents an average shortening of 2.3mm (p 0.028).

The entire patient population presented normal ROM (≥75º) in the postoperative period. The preoperative total ROM of the first MTP joint, the plantarflexion and the dorsiflexion were measured as 104º (Normal ROM), 27.7º, and 75.8º, respectively. Following the operation, the values were 96.1º, 25.2º and 70.9º. Following the operation, the total ROM in the first MTP joint was reduced by 7.4 ± 2.3º (p < 0.001).

Passive dorsiflexion decreased by 4.9 ± 1.5º ($p < 0.001$) and passive plantar flexion by 2.5 ± 0.8º ($p < 0.001$).

Pre-operatively, 58 feet (51.6%) had radiological signs of pronation. The average rotation deformity was 4.45º (Range 0 to 30; SD 6.5). Five patients (2 of 20º, 2 of 30º, and 1 of 25º) needed rotation according to recommendations. Although a rotational PeICO could have benefited these patients, radiological correction (average correction of IMA was 2.5º; HVA 9.14º and TSP 1.4 mm) and clinical outcomes and therefore no procedure was performed to correct the pronation.

The AOFAS score improved from 52.1 points preoperatively to 91.1 ($p < 0.001$) at the latest follow-up. VAS decreased from 6.3 to 1, on average. Also, FAAM ALD, FAAM Sport and MOXFQ showed statistically significant differences ($p < 0.001$) when comparing preoperative and postoperative periods. Patients found the procedure to be excellent in 82% of cases (61 feet), very good in 13.5% (10 feet) and good in 4.1% (three feet). Results are summarized in table 1.

Secondary Outcome Measures and Complications

Fluoroscopic time was 19 seconds (Range 11 to 38; SD 6.7). The average length of surgery was 25.4 minutes (Range 16 to 50; SD 6.5).

Our global complication rate was 5.26% (6 feet). We had one (0.8%) major complication: a transfer metatarsalgia (to the second metatarsal) that was successfully treated with insoles. The minor complications presented were the following: three (2.6%) soft tissue irritations that needed screw removal after at least four months postoperatively; one (0.8%) case of superficial infection that needed oral antibiotic treatment for 14 days; one case (0.8%) presented superficial skin necrosis, but no further surgical debridement was needed. We observed no other complications involving the additional procedures. Finally, there was a reoperation rate of 3.5% for screw removal.

Discussion

The most important finding of the present study is that for the first time a PS technique mimicking the intra-articular open Chevron technique showed reliable and sustained radiological, clinical and satisfaction outcomes, as showed by other percutaneous procedures. Liszka H Lucattelli G Redfern D Vernois J. Based on the results found in this study, PeICO can be indicated in mild-to-moderate HV deformities.

Reducing TSP has been proposed as a preventive factor for recurrent HV deformity. Chen et al. Chen JY recommend correcting the TSP to grade IV or less to improve functional outcomes and patient satisfaction when treating HV. Also, Kaufmann et al. Kaufmann G, Sinz S found that a chevron osteotomy can significantly correct sesamoid position using a 7-part system Hardy RH from pre- to postoperative and it remained stable throughout the follow-up. The present findings indicate that PeICO associated with PATR can achieve adequate TSP correction (average correction of 1.94 grades) without loss of correction at final follow-up. Anyway, further studies must address the correction power of PATR.

Pronation of the first metatarsal has been shown as a risk factor for the formation and progression of HV. Okuda R Ota T Wagner P Therefore, the importance of correcting malrotation to reach an adequate position and decrease the risk of HV recurrence has been progressively acknowledged. Hatch DJ Okuda R, Yasuda T This must be considered in the decision-making process, predominantly in moderate-to-severe cases. Some authors indicate rotational correction treatment when a considerable (>15º) metatarsal pronation is present. Wagner P If rotational deformity correction is needed, rotational PeICO can be made by adding a medial wedge as showed in an open chevron technique. Prado M

Excessive shortening of the first metatarsal during first metatarsal osteotomy represents a frequent risk factor for transfer metatarsalgia to the second metatarsal head. Espinosa N Nakagawa S Toth K This has been reported to occur at rates from 12% to 43%. Coughlin MJ Foran IM Recently, Kaufmann et al. showed significant shortening, with a decrease from 62.2±5.3 mm to 58.8±5.4 mm (P <0.001). Kaufmann G, Sinz S Nakagawa et al. Nakagawa S showed that postoperative shortening of the first metatarsal might lead to transfer metatarsalgia. Their results were: 60.6 ± 4.7(Range 52 to 73) in the preoperative period and 58.7 ± 4.7 (Range 45 to 68) in the postoperative period. Foran IM However, Greeff et al. found just one case of transfer metatarsalgia, with a statistically significant degree of shortening of the first metatarsal relative length, when performing a modified Lapidus procedure. The authors mentioned that the subsequent low transfer metatarsalgia rate could be attributed to the sagittal plane correction and stability. Greeff W The series presented showed one case of transfer metatarsalgia with a metatarsal shortening of 3.2 mm (before surgery it was 4.1 shorter than the second metatarsal).

Four recently published comparative studies by Brogan et al. Brogan K (Third-generation MIS distal chevron vs. Open Chevron), Kaufmann et al. Kaufmann G, Mörtlbauer L (MIS vs Open Chevron) Lai et al. Lai MC (PECA vs. Open Scarf-Akin) and Lee et al. Lee M (PECA vs. Open Scarf-Akin) have reported comparable radiological (in terms of HVA and IMA) and clinical outcomes (in terms of AOFAS and VAS) when comparing the 3G techniques with traditional open procedures. Kaufmann G et al. Kaufmann G, Mörtlbauer L showed that outcomes of a MIS technique were comparable with those of the open technique. They found no significant differences in terms of postoperative clinical outcomes within five years (VAS, AOFAS, satisfaction), radiographic outcomes, joint degeneration, or range of motion outcomes at five years of follow-up. Lee et al. Lee M reported a prospective randomized trial evaluating 25 MICA vs. 25 open surgery cases. They showed AOFAS score improvement (61.3 to 88.7) in the MIS group. Also, HVA improved from 31.4 to 7.6º and IMA from 15.6 to 6.4º. They reported 84% excellent patient satisfaction and 16% good satisfaction in the MIS group. Holme TJ Although the study presented is not comparative, it showed good-to-excellent radiological and clinical results and patient satisfaction rates.

According to some authors, a simultaneous bilateral correction has the same functional and radiographic results as unilateral surgery. Boychenko AV Carvalho P Lee KB Lim WSR Recently, Lim et al. Lim WSR found no significant differences in post-operative outcome and patient satisfaction between both groups. Our series found no differences (through radiographic corrections and clinical outcomes) between unilateral and bilateral patient outcomes. This may improve the quality of life of patients and shows promise for safely reducing costs. Molloy A

Lateral release is an additional procedure that helps osteotomies to correct HV deformities. The main indications for a lateral release are mild-to-severe hallux valgus, especially in preoperative incongruent joints. Dalmau-Pastor M, Malagelada F Del Vecchio JJ, Dalmau-Pastor M Several studies have failed to accurately describe which structures were being released or detached as soft tissue adjuvant treatments of hallux valgus. Adductor tendon percutaneous release was the most commonly used procedure to assist osteotomies in correcting HV deformities. Del Vecchio JJ, Dalmau-Pastor M Recently, PATR proved to be a reliable and accurate technique in a comparative cadaveric study, and more effective in fully releasing the adductor tendon. Dalmau-

Pastor M, Malagelada F Although the most powerful percutaneous osteotomies (e.g. MICA, subcapital) may not need a lateral release to correct HV deformity, we used lateral release as a routine procedure, as showed in table 2. In the present study, PATR was used in all patients and possibly has an effect in preventing recurrence. Further studies should assess if PATR may effectively reduce TSP, how much valgus correction power it has, and if it helps to correct proximal phalanx pronation.

Stiffness of the MTP joint may be a challenging complication after HV correction, especially after intraarticular procedures. Distal open chevron osteotomies showed rigid MTP joints between 1.13% to 27.3% of cases Bai LB Barca F Guclu B Ozkurt B Tollison ME Vopat BG First generation (1G) percutaneous osteotomies (Reverdin-Isham) revealed a reduction of the ROM by 15º, and moderate or severe stiffness (ROM <30º) in 2% to 100% of cases. Bauer T Biz C Severyns M. Also, Bosch-type procedures (2G) showed stiffness rates in 4% to 14% of cases Bia A Faour-Martín O Magnan B. 3G techniques showed the lowest rate of this postoperative complication: 0 to 7.7% Chan CX Frigg A Holme TJ Liszka H Jowett CRJ Although PeICO is a 3G intra-articular osteotomy, it showed no postoperative stiffness. The reason that explains these results may be that a dorsal capsulotomy is needed to shift the first metatarsal head and the fact that it does not need a capsulorraphy may contribute to preserve motion; patients were advised to do active and passive toe movements after four weeks.

Recently, a systematic review showed that 2G or Bosch-type osteotomies had an average complication rate of 10% (6%major and 4% minor). 3G or chevron-type procedures presented a 19% rate (8% major and 11% minor). Jeyaseelan L In the latter procedures, the authors mentioned that, if the subgroup (learning curve completed) of patients from the Jowett and Bedi study Jowett CRJ is excluded, the average complication rate reduces to 12%. Besides this, if we evaluate 2G or 3G studies over

100 feet, the complication rate goes down to 13.4% (Table 2). Agregar texto de tabla Our results gave a lower complication rate (5.26% between major and minor ones) than those of 2G or 3G type procedures. Certainly, using two or three screws Jowett CRJ Lewis TL Liszka H or not using osteosynthesis Lucattelli G may lead to more related complications (fracture of the lateral cortex, screw skin irritation and delayed bone union, respectively) and a higher reoperation rate.

The average recurrence rate with chevron-type osteotomies is 19.1% (Range, between 0 to 75.6%). Aiyer A Choi GW Jeuken RM Lagaay PM Recurrence is defined as the clinical development of HV after surgical correction (alignment). All patients in our study underwent the PeICO procedure associated with a PATR Dalmau-Pastor M, Malagelada F Del Vecchio JJ, Dalmau-Pastor M even in congruent MTP joints. This may have contributed to prevent recurrence (no cases seen so far).

Screw removal seems to be a frequent indication for a new surgical procedure in 3G procedures Holme TJ Lee M, ranging from10-24%. Recently, Holme et al. Holme TJ showed the results of a MICA procedure for HV treatment, with a complication rate of 10%, representing four patients that required Akin screw removal due to soft tissue irritation. Also, Lee et al. Lee M presented a screw removal rate of 24% (6 out of 25 patients). Our screw removal rate was 2.6%. This complication might be avoidable by using specific screws and/or getting adequate radioscopic images. The reoperation rate for Chevron-Akin is 5.56% according to Lagaay et al. Lagaay PM We found that screw removal was the most common reason for indicating a new procedure.

When performing a distal open chevron associated with a lateral release, avascular necrosis incidence varies between 1.7% and 2.8% Barca F Schneider W According to some authors, adding a lateral release may increase its occurrence. Our cohort series did not show this complication, even adding a percutaneous lateral release (PATR).

Some authors report the average mean operating time of percutaneous chevron osteotomy as 64.3 minutes Holme TJ Lai MC Lam K-LK (Range 44.3 to 94.3) to correct mild-to-severe HV deformities. PeICO proved to be a significantly faster procedure (25.4 minutes on average). Further studies should assess whether PeICO is cost-effective compared with other procedures. Lai et al. showed a fluoroscopic time of44.6 ± 5.9 seconds when performing a percutaneous Chevron-Akin osteotomy. Lai MC Recently, Palmanovich et al. showed that mean surgery time was reduced to 45 minutes, and the number of fluoroscopy expositions was decreased to 70 after two years of experience doing MICA (advanced learning curve). Palmanovich E The average fluoroscopy time of PeICO was 19 seconds. It seems that using fewer screws is crucial, making PeICO faster and dramatically diminishing the need for radiation exposure.

Limitations

This study's main limitation is the lack of a control group, which would have been useful to compare the results with open chevron osteotomies. There is also inherent selection and observer bias because the patients were recruited from a single hospital. Also, surgeries were made by an experienced surgeon. Although it can avoid a performance bias, a complete percutaneous learning curve is needed to achieve the results shown in this study. The AOFAS score was used and is not a validated assessment tool. Finally, a short-term follow-up (18 months minimum) may not show the real effect of potential complications with time.

Strengths

The study had some strengths. First, we included a large number of patients available for analysis. Second, the MOXFQ score was used which is a validated assessment tool to record patient outcomes. Complications were divided and comprehensively evaluated to make future analysis easier.

Conclusion

To our knowledge, the present study is the first to describe the radiological and clinical outcomes of a percutaneous intra-articular chevron-type osteotomy, that resembles an open chevron. PeICO combined with PATR proved to be a safe, reliable and effective technique for the correction of mild-to-moderate HV deformity. This technique presented excellent satisfaction rates at a minimum of 18 months of follow-up. It also resulted in a significantly shorter operation and fluoroscopic and a lower rate of surgical site infections when compared with other techniques.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. ICMJE forms for all authors are available online.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

References

1. Aiyer A, Shub J, Shariff R, Ying L, Myerson M. Radiographic Recurrence of Deformity After Hallux Valgus Surgery in Patients With Metatarsus Adductus. *Foot Ankle Int.* 2016 Feb;37(2):165-71. doi: 10.1177/1071100715608372.

2. 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(8):683-688. doi:10.3113/FAI.2010.0683.

3. Bauer T, de Lavigne C, Biau D, et al. Percutaneous hallux valgus surgery: a prospective multicenter study of 189 cases. *Orthop Clin North Am.* 2009;40(4):505-514

4. Bia A, Guerra-Pinto F, Pereira BS, et al. Percutaneous oste-otomies in hallux valgus: a systematic review. J Foot Ankle Surg. 2018;57(1):123-130.

5. Barca F, Busa R. Austin/chevron osteotomy fixed with bioabsorbable poly-L-lactic acid single screw. *J Foot Ankle Surg*. 1997 Jan-Feb;36(1):15-20; discussion 79-80. doi: 10.1016/s1067-2516(97)80004-x.

6. Barg A, Harmer JR, Presson AP, Zhang C, Lackey M, Saltzman CL. Unfavorable Outcomes Following Surgical Treatment of Hallux Valgus Deformity: A Systematic Literature Review. *J Bone Joint Surg Am*. 2018 Sep 19;100(18):1563-1573. doi: 10.2106/JBJS.17.00975.

7. Biz C, Fosser M, Dalmau-Pastor M, Corradin M, Rodà MG, Aldegheri R, Ruggieri P. Functional and radiographic outcomes of hallux valgus correction by mini-invasive surgery with Reverdin-Isham and Akin percutaneous osteotomies: a longitudinal prospective study with a 48-month follow-up. *J Orthop Surg Res.* 2016 Dec 5;11(1):157. doi: 10.1186/s13018-016-0491-x.

8. Boychenko AV, Solomin LN, Parfeyev SG, Obukhov IE, Belokrylova MS, Davidov DV. Efficacy of Bilateral Simultaneous Hallux Valgus Correction Compared to Unilateral. *Foot Ankle Int*. 2015 Nov;36(11):1339-43. doi: 10.1177/1071100715589174.

9. Brogan K, Lindisfarne E, Akehurst H, Farook U, Shrier W, Palmer S. Minimally invasive and open distal chevron osteotomy for mild to moderate hallux valgus. *Foot Ankle Int*. 2016;37(11):1197-1204.

10. Carvalho P, Viana G, Flora M, Emanuel P, Diniz P. Percutaneous hallux valgus treatment: Unilaterally or bilaterally. *Foot Ankle Surg*. 2016 Dec;22(4):248-253. doi: 10.1016/j.fas.2015.11.002.

11. Chan CX, Gan JZ, Chong HC, Rikhraj Singh I, Ng SYC, Koo K. Two year outcomes of minimally invasive hallux valgus surgery. *Foot Ankle Surg*. 2019 Apr;25(2):119-126. doi: 10.1016/j.fas.2017.09.007.

12. Chen JY, Rikhraj K, Gatot C, Lee JY, Singh Rikhraj I. Tibial Sesamoid Position Influence on Functional Outcome and Satisfaction After Hallux Valgus Surgery. *Foot Ankle Int.* 2016 Nov;37(11):1178-1182.

13. Choi GW, Kim HJ, Kim TS, Chun SK, Kim TW, Lee YI, Kim KH. Comparison of the Modified McBride Procedure and the Distal Chevron Osteotomy for Mild to Moderate Hallux Valgus. *J Foot Ankle Surg*. 2016 Jul-Aug;55(4):808-11. doi: 10.1053/j.jfas.2016.02.014.

14. Coughlin MJ, Jones CP. Hallux valgus: demographics, etiology, and radiographic assessment. *Foot Ankle Int*. 2007;28(7):759-777.

15. Coughlin MJ, Saltzman CL, Nunley JA II. Angular measurements in the evaluation of hallux valgus deformities: a report of the ad hoc committee of the American Orthopaedic Foot & Ankle Society on angular measurements. *Foot Ankle Int.*2002;23(1):68-74.

16. Coughlin MJ, Shurnas PS. Hallux rigidus: demographics, etiology, and radiographic assessment. Foot Ankle Int. 2003;24(10):731-743.

17. Dalmau-Pastor M, Malagelada F, Cordier G, Del Vecchio JJ, Ghioldi ME, Vega J. Anatomical Study of Minimally Invasive Lateral Release Techniques forHallux Valgus Treatment. *Foot Ankle Int*. 2020;1071100720920863. doi:10.1177/1071100720920863.

18. Del Vecchio JJ, Dalmau-Pastor M. Percutaneous Lateral Release in Hallux Valgus: Anatomic Basis and Indications. *Foot Ankle Clin*. 2020;25(3):373-383. doi:10.1016/j.fcl.2020.05.003.

19. Del Vecchio JJ, Ghioldi ME. Evolution of Minimally Invasive Surgery in Hallux Valgus. *Foot Ankle Clin*. 2020 Mar;25(1):79-95. doi: 10.1016/j.fcl.2019.10.010.

20. Del Vecchio JJ, Ghioldi ME, Uzair AE, Chemes LN, Manzanares-Céspedes MC, Dealbera ED, Dalmau-Pastor M. Percutaneous, Intra-articular, Chevron Osteotomy (PeICO) for the Treatment of Hallux Valgus: A Cadaveric Study. *Foot Ankle Int.* 2019 May;40(5):586-595. doi: 10.1177/1071100718820696.

21. Del Vecchio JJ, Ghioldi ME, Uzair AE, Chemes LN, Dealbera ED, Dalmau-Pastor, M. Percutaneous, Intra-articular, Chevron Osteotomy (PeICO) for the Treatment of Hallux Valgus. *Techniques in Foot & Ankle Surgery*. September 15, 2020. doi: 10.1097/BTF.0000000000000271.

22. Del Vecchio JJ, Ghioldi ME, Raimondi N. Osteotomía en tejadillo (chevron) con técnica mínimamente invasiva en la región distal del primer metatarsiano. Evaluación radiológica. [First metatarsal Minimally invasive Chevron osteotomy. Radiologic evaluation]. *Rev Asoc Argent Ortop Traumatol*. 2017;82(1):19-27. doi: 10.15417/633.

23. Dodwell ER, Pathy R, Widmann RF, Green DW, Scher DM, Blanco JS, Doyle SM, Daluiski A, Sink EL. Reliability of the Modified Clavien-Dindo-Sink Complication Classification System in Pediatric Orthopaedic Surgery. *JB JS Open Access*. 2018 Oct 23;3(4):e0020. doi: 10.2106/JBJS.OA.18.00020.

24. Espinosa N, Maceira E, Myerson MS. Current concept review: metatarsalgia. *Foot Ankle Int*. 2008;29(8):871-879. doi:10.3113/fai.2008.0000.

25. Faour-Martín O, Martín-Ferrero MA, Valverde García JA, Vega-Castrillo A, de la Red-Gallego MA. Long-term results of the retrocapital metatarsal percutaneous osteotomy for hallux valgus. *Int Orthop*. 2013 Sep;37(9):1799-803. doi: 10.1007/s00264-013-1934-1.

26. Foran IM, Mehraban N, Jacobsen SK, Bohl DD, Lin J, Lee S, Holmes GB, Hamid KS. Radiographic Impact of Lapidus, Proximal Lateral Closing Wedge Osteotomy, and Suture Button Procedures on First Ray Length and Dorsiflexion for Hallux Valgus. *Foot Ankle Int.* 2020 Aug;41(8):964-971. doi: 10.1177/1071100720925438.

27. Frigg A, Zaugg S, Maquieira G, Pellegrino A. Stiffness and Range of Motion After Minimally Invasive Chevron-Akin and Open Scarf-Akin Procedures. *Foot Ankle Int.* 2019 May;40(5):515-525. doi: 10.1177/1071100718818577.

28. Garcés JB, Winson I, Goldhahn S, et al. Reliability, validity and responsiveness of the Spanish Manchester-Oxford Foot Questionnaire (MOXFQ) in patients with foot or ankle surgery. *Foot Ankle Surg*. 2016;22(1):59-70. doi:10.1016/j.fas.2015.09.004.

29. Greeff W, Strydom A, Saragas NP, Ferrao PNF. Radiographic Assessment of Relative First Metatarsal Length Following Modified Lapidus Procedure. *Foot Ankle Int*. 2020 Aug;41(8):972-977. doi: 10.1177/1071100720924016.

30. Guclu B, Kaya A, Akan B, Koken M, Kemal Us A. Stabilization of chevron bunionectomy with a capsuloperiosteal flap. *Foot Ankle Int.* 2011 Apr;32(4):414-8. doi: 10.3113/FAI.2011.0414.

31. Hardy RH, Clapham JC. Observations on hallux valgus. *J Bone Joint Surg Br.* 1951;33(3):376-391.

32. Hatch DJ, Santrock RD, Smith B, Dayton P, Weil L Jr. Triplane Hallux AbductoValgus Classification. *J Foot Ankle Surg*. 2018 Sep - Oct;57(5):972-981. doi: 10.1053/j.jfas.2018.02.008.

33. Holme TJ, Sivaloganathan SS, Patel B, Kunasingam K. Third-Generation Minimally Invasive Chevron Akin Osteotomy for Hallux Valgus. *Foot Ankle Int*. 2020;41(1):50-56. doi:10.1177/1071100719874360.

34. Jeuken RM, Schotanus MG, Kort NP, Deenik A, Jong B, Hendrickx RP. Long-term Follow-up of a Randomized Controlled Trial Comparing Scarf to Chevron

Osteotomy in Hallux Valgus Correction. *Foot Ankle Int*. 2016 Jul;37(7):687-95. doi: 10.1177/1071100716639574.

35. Jeyaseelan L, Malagelada F. Minimally Invasive Hallux Valgus Surgery-A Systematic Review and Assessment of State of the Art. *Foot Ankle Clin*. 2020 Sep;25(3):345-359. doi: 10.1016/j.fcl.2020.05.001.

36. Jowett CRJ, Bedi HS. Preliminary Results and Learning Curve of the Minimally Invasive Chevron Akin Operation for Hallux Valgus. *J Foot Ankle Surg*. 2017;56(3):445-452. doi:10.1053/j.jfas.2017.01.002

37. Kaufmann G, Mörtlbauer L, Hofer-Picout P, Dammerer D, Ban M, Liebensteiner M. Five-Year Follow-up of Minimally Invasive Distal Metatarsal Chevron Osteotomy in Comparison with the Open Technique: A Randomized Controlled Trial. *J Bone Joint Surg Am*. 2020;102(10):873-879. doi:10.2106/JBJS.19.00981.

38. Kaufmann G, Sinz S, Giesinger JM, Braito M, Biedermann R, Dammerer D. Loss of Correction After Chevron Osteotomy for Hallux Valgus as a Function of Preoperative Deformity. *Foot Ankle Int*. 2019;40(3):287-296. doi:10.1177/1071100718807699.

39. Klugarova J, Hood V, Bath-Hextall F, Klugar M, Mareckova J, Kelnarova Z. Effectiveness of surgery for adults with hallux valgus deformity: a systematic review. *JBI Database System Rev Implement Rep*. 2017;15(6):1671-1710. doi:10.11124/JBISRIR-2017-003422.

40. Lagaay PM, Hamilton GA, Ford LA, Williams ME, Rush SM, Schuberth JM. Rates of revision surgery using Chevron-Austin osteotomy, Lapidus arthrodesis, and closing base wedge osteotomy for correction of hallux valgus deformity. *J Foot Ankle Surg*. 2008 Jul-Aug;47(4):267-72. doi: 10.1053/j.jfas.2008.03.002.

41. Lai MC, Rikhraj IS, Woo YL, Yeo W, Ng YCS, Koo K. Clinical and Radiological Outcomes Comparing Percutaneous Chevron-Akin Osteotomies vs Open Scarf-Akin Osteotomies for Hallux Valgus. *Foot Ankle Int*. 2018;39(3):311-317. doi:10.1177/1071100717745282.

42. Lam K-LK, Kong S-W, Chow Y-H. Percutaneous chevron osteotomy in treating hallux valgus: Hong Kong experience and mid-term results. *J Orthop Trauma Rehabil.* 2015;19(1):25-30.

43. Lee KB, Hur CI, Chung JY, Jung ST. Outcome of unilateral versus simultaneous correction for hallux valgus. *Foot Ankle Int*. 2009 Feb;30(2):120-3. doi: 10.3113/FAI.2009.0120.

47. Lee M, Walsh J, Smith MM, Ling J, Wines A, Lam P. Hallux Valgus Correction Comparing Percutaneous Chevron/Akin (PECA) and Open Scarf/Akin Osteotomies. *Foot Ankle Int.* 2017 Aug;38(8):838-846. doi: 10.1177/1071100717704941.

48. Lewis TL, Ray R, Miller G, Gordon DJ. Third-Generation Minimally Invasive Chevron and Akin Osteotomies (MICA) in Hallux Valgus Surgery: Two-Year Follow-up of 292 Cases. *J Bone Joint Surg Am*. 2021 Mar 25. doi: 10.2106/JBJS.20.01178.

49. Lim WSR, Rikhraj IS, Koo KOT. Simultaneous bilateral hallux valgus surgery: Percutaneous or conventional? Early results of a matched study from a tertiary institution. *Foot Ankle Surg*. 2020;S1268-7731(20)30079-5. doi:10.1016/j.fas.2020.04.014.

50. Liszka H, Gądek A. Percutaneous Transosseous Suture Fixation of the Akin Osteotomy and Minimally Invasive Chevron for Correction of Hallux Valgus. *Foot Ankle Int*. 2020;1071100720935036. doi:10.1177/1071100720935036.

51. Lucattelli G, Catani O, Sergio F, Cipollaro L, Maffulli N. Preliminary Experience With a Minimally Invasive Technique for Hallux Valgus Correction With No Fixation. *Foot Ankle Int*. 2020 Jan;41(1):37-43. doi: 10.1177/1071100719868725.

52. Magnan B, Bortolazzi R, Samaila E, Pezzè L, Rossi N, Bartolozzi P. Percutaneous distal metatarsal osteotomy for correction of hallux valgus. Surgical technique. *J Bone Joint Surg Am*. 2006 Mar;88 Suppl 1 Pt 1:135-48. doi: 10.2106/JBJS.E.00897.

53. Malagelada F, Sahirad C, Dalmau-Pastor M, et al. Minimally invasive surgery for hallux valgus: a systematic review of current surgical techniques. *Int Orthop*. 2019;43(3):625-637. doi:10.1007/s00264-018-4138-x.

54. Matar HE, Platt SR. Overview of randomised controlled trials in hallux valgus surgery (2,184 patients). *Foot Ankle Surg*. 2020;S1268-7731(20)30078-3. doi:10.1016/j.fas.2020.04.013.

55. Molloy A, Heyes G. Cost-Effectiveness of Surgical Techniques in Hallux Valgus. *Foot Ankle Clin*. 2020;25(1):19-29. doi:10.1016/j.fcl.2019.10.005.

56. Nakagawa S, Fukushi J, Nakagawa T, Mizu-Uchi H, Iwamoto Y. Association of Metatarsalgia After Hallux Valgus Correction With Relative First Metatarsal Length. *Foot Ankle Int*. 2016;37(6):582-588. doi:10.1177/1071100716634792

57. Okuda R, Kinoshita M, Yasuda T, Jotoku T, Kitano N, Shima H. The shape of the lateral edge of the first metatarsal head as a risk factor for recurrence of hallux valgus.*J Bone Joint Surg Am.* 2007;89(10):2163–72.

58. Okuda R, Yasuda T, Jotoku T, Shima H. Supination stress of the great toe for assessing intraoperative correction of hallux valgus. *J Orthop Sci.* 2012 Mar;17(2):129-35. doi: 10.1007/s00776-011-0182-8.

59. Ota T, Nagura T, Kokubo T, Kitashiro M, Ogihara N, Takeshima K, Seki H, Suda Y, Matsumoto M, Nakamura M. Etiological factors in hallux valgus, a three-dimensional analysis of the first metatarsal. *J Foot Ankle Res*. 2017 Oct 10;10:43. doi: 10.1186/s13047-017-0226-1.

60. Ozkurt B, Aktekin CN, Altay M, Belhan O, Tabak Y. Range of motion of the first metatarsophalangeal joint after chevron procedure reinforced by a modified capsuloperiosteal flap. *Foot Ankle Int*. 2008 Sep;29(9):903-9. doi: 10.3113/FAI.2008.0903.

61. Palmanovich E, Ohana N, Atzmon R, Slevin O, Brin Y, Feldman V, Segal D. MICA: A Learning Curve. *J Foot Ankle Surg*. 2020 Jul-Aug;59(4):781-783. doi: 10.1053/j.jfas.2019.07.027.

62. Prado M, Baumfeld T, Nery C, Mendes A, Baumfeld D. Rotational biplanar Chevron osteotomy. *Foot Ankle Surg*. 2020;26(4):473-476. doi:10.1016/j.fas.2019.05.011.

63. Raikin SM, Miller AG, Daniel J. Recurrence of hallux valgus: a review. *Foot Ankle Clin.* 2014;19(2):259-274. doi:10.1016/j.fcl.2014.02.008.

64. Redfern D, Vernois J. Minimally invasive chevron Akin (MICA) for correction of hallux valgus. *Tech Foot Ankle Surg*. 2016;15(1):3-11. doi: 10.1097/BTF.0000000000000102.

65. Schneider W, Aigner N, Pinggera O, Knahr K. Chevron osteotomy in hallux valgus. Ten-year results of 112 cases. *J Bone Joint Surg Br*. 2004;86(7):1016-1020. doi:10.1302/0301-620x.86b7.15108.

66. Severyns M, Carret P, Brunier-Agot L, Debandt M, Odri GA, Rouvillain JL. Reverdin-Isham procedure for mild or moderate hallux valgus: clinical and radiographic outcomes. *Musculoskelet Surg.* 2019 Aug;103(2):161-166. doi: 10.1007/s12306-018-0563-7.

67. Sink EL, Leunig M, Zaltz I, Gilbert JC, Clohisy J; Academic Network for Conservational Hip Outcomes Research Group. Reliability of a complication classification system for orthopaedic surgery. *Clin Orthop Relat Res*. 2012 Aug;470(8):2220-6. doi: 10.1007/s11999-012-2343-2.

68. Sutton RM, McDonald EL, Shakked RJ, Fuchs D, Raikin SM. Determination of Minimum Clinically Important Difference (MCID) in Visual Analog Scale (VAS) Pain and Foot and Ankle Ability Measure (FAAM) Scores After Hallux Valgus Surgery. *Foot Ankle Int*. 2019 Jun;40(6):687-693. doi: 10.1177/1071100719834539.

69. Tollison ME, Baxter DE. Combination chevron plus Akin osteotomy for hallux valgus: should age be a limiting factor? *Foot Ankle Int.* 1997 Aug;18(8):477-81. doi: 10.1177/107110079701800804.

70. Toth K, Huszanyik I, Kellermann P, Boda K, Rode L. The effect of first ray shortening in the development of metatarsalgia in the second through fourth rays after metatarsal osteotomy. *Foot Ankle Int.* 2007;28(1):61-63. doi:10.3113/FAI.2007.0011.

71. Vernois J, Redfern D. Percutaneous chevron; the union of classic stable fixed approach and percutaneous technique. *FußSprunggelenk*. 2013;11(2):70-75.

72. Vopat BG, Lareau CR, Johnson J, Reinert SE, DiGiovanni CW. Comparative study of scarf and extended chevron osteotomies for correction of hallux valgus. *Foot Ankle Spec*. 2013 Dec;6(6):409-16. doi: 10.1177/1938640013508431.

73. Wagner P, Wagner E. Is the Rotational Deformity Important in Our Decision-Making Process for Correction of Hallux Valgus Deformity?. *Foot Ankle Clin.* 2018 Jun;23(2):205-217. doi: 10.1016/j.fcl.2018.01.009.

74. Yamaguchi S, Sasho T, Endo J, Yamamoto Y, Akagi R, Sato Y, Takahashi K. Shape of the lateral edge of the first metatarsal head changes depending on the rotation and inclination of the first metatarsal: a study using digitally reconstructed radiographs. *J Orthop Sci.* 2015 Sep;20(5):868-74. doi: 10.1007/s00776-015-0749-x.

75. Yassin M, Bowirat A, Robinson D. Percutaneous surgery of the forefoot compared with open technique - Functional results, complications and patient satisfaction. *Foot Ankle Surg*. 2020;26(2):156-162. doi:10.1016/j.fas.2019.01.006.