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

Introduction

Minimally invasive surgery (MIS), also known as percutaneous surgery has experienced a vertiginous and sustained growth for the treatment of foot and ankle problems, especially in the last decade. This is supported by numerous studies including clinical series Bauer T, Biz C, comparative studies Brogan K, Lindisfarne E; Lee M, Walsh J, Kaufmann G technique reports David Redfern and Joel Vernois and radiological validations Huang PJ.

Recently, three systematic reviews concluded MIS is a safe and reliable procedure for hallux valgus surgery Bia A; Caravelli S. Malagelada F, Sahirad C. Three cadaveric studies considered percutaneous forefoot surgery a safe technique Dhukaram V, Yañez Arauz JM; Kaipel M, Teoh KH which is accordant with clinical studies.

MIS forefoot surgery is experiencing a sustained and responsible growth based on Third Generation (TG) techniques. While first Isham S; Bauer T and second Bosch P; Magnan B, Pezze L generations continue to maintain their validity and indications, little by little they are leaving room for the emergence of new techniques. TG surgeries Brogan K, Voller T; Lucas y Hernandez J; Vernois J, Redfern D. Walker R, Redfern D involve procedures based on the design of open chevron osteotomies and can be divided on intra and extra-articular procedures.

A *Percutaneous, Intraarticular, Chevron Osteotomy* (PEICO) for the treatment of hallux valgus was recently described and showed good potential for correction del Vecchio JJ. To date no validation anatomical studies are available for this technique, despite the technique is 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 to define safe zones in a PEICO procedure, as well as assess the accuracy of the osteotomy itself.

Materials and methods

Eight feet (four right and four left), from below-knee fresh frozen specimens were selected. The cadavers included three men and five women with an average age of 38 (SD 15,9) years, six left and two right feet. Three specimens had mild and five had moderate HV deformity. Ethical approval was obtained from our institution with Institutional Review Board number 00003099. The demographic data is shown in Table 1.

Specimens were not selected if they had evident signs of ulcers, deformities or surgical incisions from previous foot and/or ankle procedures.

One surgeon (DV, JJ) performed all the procedures. The surgeon was specialized in foot and ankle surgery with over ten years of experience in percutaneous procedures. In each foot, JJDV performed a PEICO on the 1st ray and an adductor tenotomy and lateral release (latero-plantar capsule) of the 1st MTP joint (First web space portal).

To evaluate the safety of the procedure the following data was obtained:

1. Distance between (DB) P1 and lateral border of the *extensor hallucis longus (EHL*T*);*
2. DB P1 and dorsomedial digital nerve (DMDN)
3. DB P1 and MTPJ
4. DB P2 -or osteosynthesis portal- and MTPJ
5. DB P2 and lateral border of *EHL*T
6. DB P2 and DMDN.

This anatomical study also assessed if any arterial plexus damage was present by examination of indemnity of the soft tissue and 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 osteotomy in the sagittal plane (Reproducibility of a single surgeon) and IMA and HV 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 x 6 cm that only involved the skin.

Two independent observers made all the assessments and each one made two measurements of each parameter.

The following equipment is required:

- Burrs: Isham Straight Flute Shannon (ISFS) and Wedge Burr 3.1.
- Instruments: Regular Mini Blade #6400, Freer elevator, bone Rasp (Small)
- Mini C-arm (preferable) or C-arm
- 2 mm K-wire
- 3.0 conical cannulated screw

The technique can be divided into the following steps:

1. A 2.0 mm x 20 cm K-wire is placed percutaneously in the medial region of the hallux distal phalanx. It must slide until it stops at the medial surface of the first MTP joint.

2. A 3-mm medial portal (P1) is made with a MIS surgical blade in the limit between the proximal third and the distal two-thirds of the 1MT head, using C-arm to corroborate the correct position.
3. A percutaneous dorsal capsular detachment is then performed to allow cephalic mobilization, similar to open chevron. The burr (ISFS) is inserted with a medial-to-lateral course through 1MT head in order to create the apex of PICO.
4. Then the dorsal limb (DL) of the PICO is made perpendicular to the 1MT diaphysis creating a 10 to 20° angle from the apex point. Great care is required to elude damage to the DMDN. The plantar limb (PL) is performed from the apex point in a proximal direction parallel to the floor. The angle created by the two limbs must be between 80 and 100 degrees.
5. The lateral shift of the 1MT (up to 50%) is carried out with a 2 mm Kirschner-wire and an angled stem probe ("Bosch method" Bösch P). The probe must be inserted through P1 and not through an accessory portal like as described for other procedures. Then, the K-wire is advanced with the aid of a hammer while then the surgeon applies an external rotational maneuver force to displace the head and is removed afterwards.
6. Then, through a dorsomedial portal (P2≅15 mm proximal and 3 mm dorsal to the P1), a guidewire is placed in order to fix the osteotomy. The stabilization is performed preferably through a 3.0 mm headless screw fixation from dorsal-medial to lateral-plantar direction in a 45º angulation on the AP view. After the guidewire is removed, resection of the remnant bunion is performed through the P2 with a 3.1 wedge Burr.
7. Percutaneous adductor tenotomy (PAT) and lateral release (LR): it must never be made before performing the PICO, as it may cause loss of control of the 1MT

head. This step involves the tenotomy of the adductor hallucis tendon and the release of the latero-plantar capsule. This is completed using a MIS blade that is introduced into the first web space through an accessory portal (P3). In order to section the sesamoid phalangeal ligament, the blade is rotated towards the first web space while the hallux is forced into varus.

Statistical Analysis

Statistical graphics and summaries measures like mean, median and standard deviation were used to describe the data. Linear mixed effects models were conducted to control the observers and individuals influence. To assess the significance of the model coefficients probability ratio test were conducted. Statistical analysis was performed using R language version 3.4.3. A p value of less than .05 was considered statistically significant.

Results

After completing the surgical procedure, all specimens were dissected. The essential result of this study was a comprehensive summary of the anatomical structures facing a possible damage following percutaneous HV treatment by doing the PEICO technique.

The results of the safety measurements were as follow:

1. Average: 17,64 (range: 12,72-21,31).

2. Average: 7,29 (range:1,62-10,41).

3. Average: 15,72 (range: 9,48-20,52).

4. Average: 25,55 (range: 22,06-30,44).

5. Average: 12,77 (range: 8,04-16,71).

6. Average: 4,14 (range:1,72-8,20). Figura de disección y Figura de estadista

There were no iatrogenic injuries. Nevertheless, the DB OP and DMDN showed the lowest average distance. The results data are shown in Table 2.

With respect of the osteotomy angulation in the sagittal plane (Reproducibility), the average was: 85,62º (range: 81-95). Mean preoperative intermetatarsal angle (IMA) was 9,75 ° (range: 8-18°), and postoperatively the mean IMA was 8° (range: 4-13°). Before surgery the mean hallux valgus angle (HVA) was 22° (range: 13-40°) and the average postoperative HVA was 13,5° (range: 6-34°).

Discussion

The most important finding of the study is that PEICO is a safe procedure and that in trained hands intra-surgical results can be reliably reproduced.

In a previous publication, the radiological outcomes of PEICO in 21 patients (24 feet) have been reported. del Vecchio All patients were diagnosed of moderate hallux valgus (HV); mean follow-up was 11,59 81 months (6-18, SD 4,67). Mean preoperative intermetatarsal angle (IMA) between M1 and M2 was 12.46° (range: 11-15°, SD 1.03). Postoperatively, the IMA was 8.13° (range: 5-10°; SD 1.16), with an average angular correction of 4.33°. The mean hallux valgus angle (HVA) was 33.96° (20-40°; SD 4.93) before surgery and the average postoperative HVA was 8.16° (range: 3-15°, SD 2.86), thus obtaining an average improvement of 25.86°. No metatarsal shortening or recurrence was observed. The authors concluded that PEICO is effective for the treatment of HV, with mid-term satisfactory angular correction.

The overall complication rate in percutaneous surgery continues to be high, ranging from 6.9% to 29.4% Bauer T; Radwan YA, Malagelada F, Sahirad C, Iannò B; Bia A Brogan K, Lindisfarne E and this is a special concern when they are done by

unexperienced surgeons. Kaipel M; Trnka HJ. The presented technique showed no macroscopic lesions. In any case, it has the disadvantage of being a cadaveric study and thus not being able to show possible complications with clinical repercussions (infection, avascular necrosis, neuritis, HV recurrence, etc).

The DMDN and dorsomedial digital nerve (DLDN) Dhukaram V, Yañez Arauz JM are at risk during percutaneous forefoot surgery. Although nerve injury may not produce representative symptoms, neuroma generation may have a higher impact on patients' satisfaction and require revision procedures. Nerve injury rates of 2% to 15% have been reported. Magnan, B; Samaila, E; Teoh KH. This study showed no DLDN nor DMDN lesions. Nevertheless, the distance between P2 and the DMDN showed the lowest average distance: 4,14 mm. Recently, Kaipel et. al Kaipel M found 20% of traumatic nerve lesions when performing a percutaneous Bosch osteotomy in a cadaveric study that divided into two surgical groups (experienced surgeon and untrained residents, 10 to 40% respectively); this seem to be considerably higher when compared to 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´s method may be applied Malagelada F. This accurately describes the position of the DLDN and DMDN, that were described frequently between 10 o'clock and 2 o'clock. This system represents a useful instrument in percutaneous surgery. Also, the dorsal partial capsular detachment described did not injured neither the DLDN nor the DMDN.

The crucial blood provision to the 1st MTT head enters through a plexus located at the plantar side of the 1st MTT neck just proximal to the capsular insertion (Surg Radiol Anat. 2009 Apr;31(4):271-7. doi: 10.1007/s00276-008-0441-3. Epub 2008 Nov 21. The microvascular anatomy of the metatarsal bones: a plastination study. Rath B1,

Notermans HP, Franzen J, Knifka J, Walpert J, Frank D, Koebke J.). This supply could be injured while performing a Chevron technique and could produce an avascular necrosis (AVN) of the first MTT head. AVN is the most serious adverse effect following a chevron osteotomy, with a reported incidence of 4 to 20%. Green MA Worrell JB. In 1994, Johnson et al. modified the orientation of the dorsal branch to create a 90° angle to minimize the risk of AVN. Clinical and anatomical studies recommend to perform the osteotomy with a long plantar arm exiting proximal to the capsular attachment Malal JJG. Dhukaram et al. found no injury of the capsule and soft tissue sleeve around the 1st MTT head, and therefore concluded that no injury was caused. Dhukaram V. Donnelly RE; Resch S. In addition, although a greater correction can be achieved with an extensively lateral release, this can increase the risk of AVN up to 40%. However, in other studies no such complication has been found. Redfern D, Gill I; Pochatko DJ. In PEICO a lateral release through a 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 injury rates ranging from 0 to 5% have been described after foot percutaneous surgical techniques. National Institute for Health and Clinical Excellence; Teoh KH Dhukaram et al. Dhukaram V. Previous studies showed no tendon injuries in their study including MICA technique. However, tendon lesions - three cases of damage of plantar EHL sheet - seem more frequent Yañez Arauz JM if an Akin osteotomy was performed. 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. *EHL* is especially at risk while performing the dorsal portion of the PEICO. To attenuate the risk, leaving the joint in a 20-30 degrees of dorsiflexion is recommended to reduce the tension of the tendon while doing the osteotomy.

When PEICO is performed the angulation described by the cuts was found to be in the correct plane. As showed on results, the average angulation of the osteotomy was 85,62º, while 90 degrees are recommended on published studies. Donnelly RE; Vienne P This difference may be attributable to the fact that percutaneous surgery is performed without direct visualization of the bone. Nevertheless, angulation is close enough to 90º to prove the effectiveness of the technique, although it has to be taken in account that it was performed by an experienced open and MIS foot and ankle surgeon. Figura de la angulación de osteotomia

Stable fixation is imperative in preserving PEICO´s position. There is no need to cross the lateral cortex of the distal metaphysis and/or use of two screws to provide secure angular stability, as other techniques require Redfern D, Gill I; Walker R, Redfern D. Some procedures use one screw and an endomedular K-wire to achieve stability. Brogan K, Voller T. The technique described only needs one screw, similarly to the one used in open surgery.

Adductor tenotomy and latero-plantar capsulotomy was performed by positioning the blade at the level of the joint under image intensifier control. Although some MIS procedures do not seem to need lateral release Biz, C., Corradin; Giannini, S., Vannini, F; Maffulli, N., Longo, U.G; Lin, Y.C., others only perform the adductor´s tenotomy and a partial lateral capsule release. Díaz Fernández, R.; Martínez-Nova, A. The precise indication of those who can benefit from this procedure is still a matter of discussion Lucas y Hernandez J, Brogan K, Lindisfarne E. In addition, it should be defined which patient needs an adductor´s tendon release and which one requires an extended lateral release.

Considering the indications and potential advantages of percutaneous surgery, some authors 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: MICA *("Minimally Invasive Chevron Akin"*) is performed at the neck of the first metatarsal (extra-articular) and requires two screws for the stabilization of the osteotomy associated with an Akin osteotomy, Vernois J, Redfern D Jowett CRJ, Bedi HS, Redfern D, Gill I. It showed good to excellent results. According to the authors the development of this fixation (MICA) allows it to be used in severe HV deformities. This osteotomy can be laterally displaced up to 100% and offers a valid technique for all degrees of hallux valgus. PECA (*Percutaneous Chevron/Akin*): technically identical to MICA, this technique showed comparable outcomes to the new technique (equated to open Scarf/Akin). Lee M. MIS Chevron recently described by Brogan et al. needs one screw and K-wire to provide stability Brogan K, Lindisfarne E; Brogan K, Voller T. In a comparative study no differences in complications were found between MIS Chevron and Open Chevron, thus proving that both are safe procedures with good clinical outcomes for symptomatic mild-to-moderate hallux valgus. PERC (*Percutaneous, extra-articular reverse-L Chevron osteotomy*): also performed on the metaphysis of the first metatarsal (1MT) Lucas y Hernandez J, the main difference with 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 advantage of the PEICO technique compared to the other third generation techniques are the following: greater intrinsic stability due to a greater bone contact surface, the need for a single screw for its stabilization and the consequent shorter surgical time, associated with less complications.

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.). On the other hand, it is designed not to mimic complications like AVN Potenza V, recurrence and reoperation van Groningen B; Pentikainen I , Second Metatarsal Transfer Lesions Ahn J, and radiological hallux varus Choi YR, among others.

Some limitations exist in our study. One is the fact that this was a cadaveric study and that the freezing process may create changes in the tissue volume. In addition, studies assessing clinical outcomes and complications of this novel technique are needed.

Conclusion

There is no doubt that third generation techniques are the future of percutaneous hallux valgus surgery, as they are useful, effective and (might be) easier than open procedures. We emphasize that percutaneous surgery has an extensive learning curve and therefore it may be difficult to imitate the results showed on published data.

PEICO offers advantages over other techniques described since it does not need fixation with two screws, which results in a shorter surgical time and complication rate and may decrease costs. In addition, as it is done on the head of the 1MT, it offers greater stability and involves fewer surgical steps. Nevertheless, clinical data are needed to continue validating the technique, as well as to incorporate a control group or comparative Quality of life (QOL) studies.

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