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# Evaluation of first metatarsal head declination through a modified distal osteotomy in hallux rigidus surgery. A cadaveric model

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ABSTRACT

*Background:* First metatarsal osteotomies have been described for treatment of hallux rigidus. Most of these techniques result in declination of the first metatarsal head through shortening of the metatarsal and transfer metatarsalgia may result.

Our objective was to evaluate the declination effect of a distal metatarsal osteotomy when different angulations and lateral translations are applied.

*Materials and methods:* A cadaveric study was conducted performing a modified distal oblique osteotomy, which produces head declination while limiting shortening. Several transverse inclination angles (0–10–20–30–40°) were used. Thereafter, plantar translation of the metatarsal head was registered at different lateral displacements (1, 3, 5 mm).

*Results:* Twenty-two specimens were included. Three feet were operated on with a 0° of angulation in the transverse plane, 6 with 10°, 5 with 20°, 5 with 30°, and 3 with 40°. Head declination significantly increased with higher angulation and with greater lateral translations ($p < 0.001$), but the interrelationship between these two variables did not achieve statistical significance ($p = 0.597$).

In regards to angulation, significant differences in head declination were found between 0° (0.1–0.7 mm), 10°–20° (0.5–1.2 mm) and 30°–40° (1.3–2.4 mm). The metatarsal sesamoid joint was compromised when the osteotomy was performed at a 40° inclination angle.

*Conclusions:* Metatarsal head declination is determined by the inclination angle of the oblique limb of the osteotomy and lateral displacement of the metatarsal head. Our results suggest that the effect of lateral displacement is an independent factor from angulation.

The latter may impact surgery planning and may improve clinical outcome by selecting a safer inclination angle when lateral displacement of the metatarsal head is being considered.

*Level of evidence:* Level II-A, systematic review with homogeneity of cohort studies.

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## 1. Introduction

The hallux rigidus or limitus is the second most frequent forefoot pathology, overtaken only by hallux valgus [1]. Although etiology and biomechanics of this problem remain poorly understood, reports performing osteotomies on the first metatarsal that pursue declination of the metatarsal head have demonstrated satisfactory functional outcomes [2,3]. However, the precise declination produced by the osteotomy continues to be subjectively estimated, primarily due to the scant objective parameters to quantify it.

A myriad of first metatarsal osteotomies have been described to treat hallux rigidus [1,2,4–10]. All of these osteotomies attempt to relocate the head of the first metatarsal in the center of the proximal phalanx of the hallux. Relocation is obtained through declination of an abnormally elevated metatarsal head and thus improving dorsiflexion of the first metatarsophalangeal joint [7]. However, this biomechanical advantage is achieved through shortening of the metatarsal length and therefore,

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the consequent risk of central metatarsalgia needs to be considered. This risk is especially true in the index minus forefoot pattern.

To address the resultant metatarsal shortening, a modification of these distal metatarsal osteotomies has been proposed [11]. In order to efficiently decline the metatarsal head while controlling metatarsal length, an oblique osteotomy in both transverse and sagittal plane can be performed. This action yields lowering by means of a lateral translation of the metatarsal head. A dorsal vertical cut is associated to restrict shortening and prevent rotation. Therefore, a tridimensional correction of the deformity attempts to improve biomechanical conditions, range of motion and to decrease patient's symptoms.

The objective of this study is to evaluate, in a cadaveric model, the declination of the first metatarsal head when different osteotomy inclination angles and lateral translations of a modified distal oblique osteotomy are applied.

## 2. Materials and methods

Twenty-six fresh frozen specimens corresponding to the distal third of the tibia, ankle and foot were donated from the Human Anatomy Department. Donor's clinical information was not available for the investigators.

Exclusion criteria included: specimens with congenital or acquired deformities of the first ray or first metatarsophalangeal joint (one foot with evidence of Brandes–Keller–Lelièvre arthroplasty), inadequate bone quality preventing stable fixation of the osteotomy or precise measurement determination (2 ft); and intraoperative metatarsal fracture during osteotomy performance (one foot). Consequently, twenty-two specimens conformed the study group.

### 2.1. Surgical technique

A medial approach centered over the metatarsophalangeal joint was extended from 2 centimeters distal to the joint line to 3 cm proximal. After performing a longitudinal capsulotomy, the medial and central insertion of the plantar fascia as well as the flexor hallucis brevis insertion were then released.

Plantar vessels that irrigate the first metatarsal head were identified. A minimal bunionectomy was performed and 1.8 mm K-wire was driven into the center of the metatarsal head, parallel to plantar cortex of the first ray. This wire was used as a guide for all measurements. The perpendicular distance from this wire to the dorsal cortex of the first metatarsal head was measured with a Vernier's caliper (zero reading + 0.05 mm) and registered as X1 value (Figs. 1 and 2A).

Osteotomy's starting site was marked at 10 mm from the first metatarsophalangeal (MTP) articular line in the dorsal aspect of the metatarsal head (Fig. 3A). A second K wire was placed perpendicular to the second metatarsal, 1 mm inferior to the dorsal cortex and at 10 mm from the articular line. This wire guided angulation for the oblique osteotomy cut (Fig. 3B) and was placed with 0°, 10°, 20°, 30° or 40° of angulation with respect to the first K wire, in the coronal plane (Fig. 4). The exit site was marked 30 mm proximal to the articular site and the plantar vessels, in the plantar cortex of the first metatarsal shaft (Fig. 3C).

The osteotomy was then performed following the planned traces. The first cut was made in the transverse plane in an oblique manner from the medial aspect of the metatarsal head in a dorsal-distal to plantar-proximal direction. This cut was initiated 1 mm inferior to the dorsal cortex and at 10 mm from the joint line and accomplished at 30 mm from the joint line in the plantar cortex (Fig. 1). This part of the osteotomy was performed at different angulations (0°, 10°, 20°, 30° and 40°).

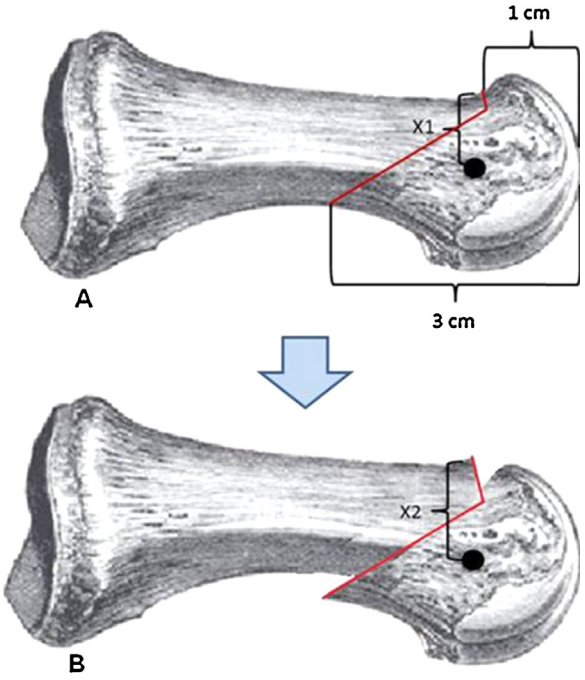



**Fig. 1.** Osteotomy design, lateral view: (A) Reference marks for osteotomy performance and measurement of X1 distance prior to osteotomize. (B) Final position of the osteotomy and measurement of head declination (X2).

Next, the second limb was made in the dorsal cortex of the first metatarsal at 10 mm from the MTP joint line. Direction of these cut was perpendicular to the second metatarsal (Figs. 1 and 5). Following the osteotomy, bone fragments were freed using chisels. The objective of this part of the osteotomy is to control metatarsal shortening and corresponds to a modification to the original

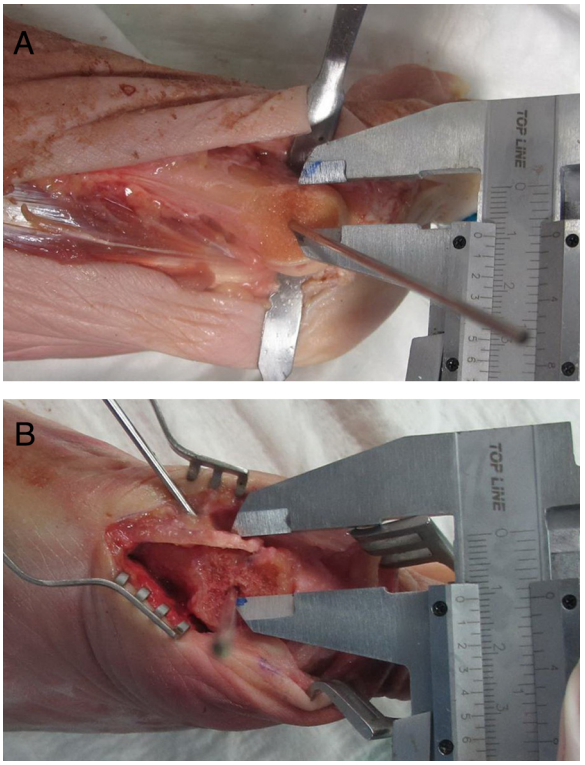



**Fig. 2.** A Intraoperative measurement of head declination before osteotomy (X1). Fig. 2 B Intraoperative measurement of head declination after osteotomy (X2).

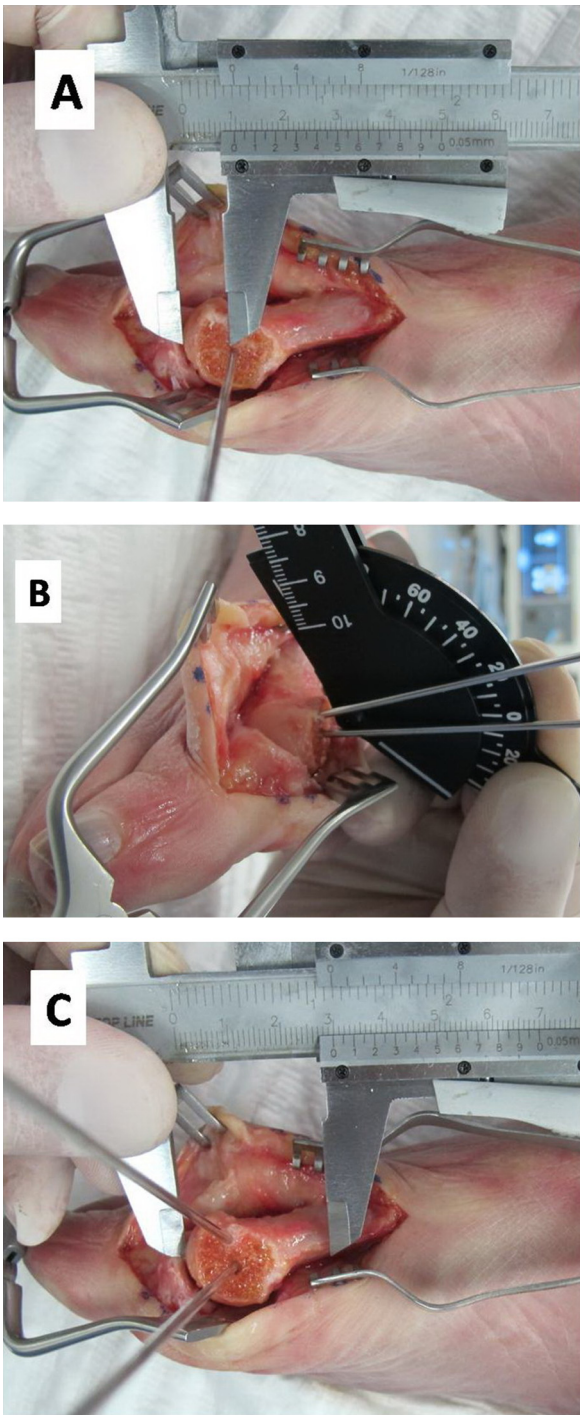



**Fig. 3.** A Osteotomy performance: A guiding K-wire is inserted into the center of the metatarsal head and the osteotomy start at 10 mm proximal from the first metatarsophalangeal articular line in the dorsal aspect of the metatarsal head.
Fig. 2 B A second K wire is inserted with the planned angulation respect from the first K wire.
Fig. 2 C Osteotomy exit site is measured 30 mm proximal to the joint line and the plantar vessels for the metatarsal head.

osteotomy. All the osteotomies were performed with a 9.4 × 25.5 × 0.4 mm mini saw and a Dyonics Power Drill® (Smith & Nephew®). A transmetatarsal lateral release was then performed to release the lateral capsule, allowing the lateral translation of the metatarsal head and centering of the sesamoids, if necessary [12].

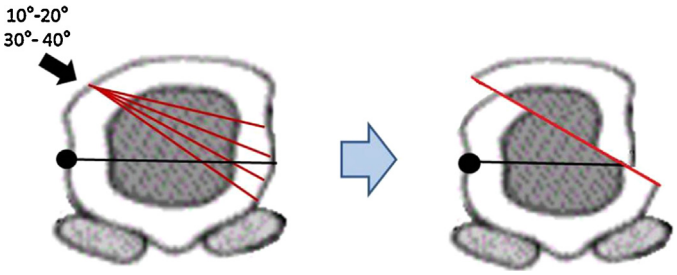



**Fig. 4.** Osteotomy planning in the coronal view and different angulation of the oblique trace.

Finally, the desired lateral translation was realized in a progressive manner (1, 3 and 5 mm) and the osteotomy fixed with a 1.8 mm K wire from dorsal to plantar (Figs. 4 and 6).

### 2.2. First metatarsal declination

Distance between the K wire located in the center of the head and the dorsum of the metatarsal was measured (X2 distance), (Figs.1 and 5B) to determine the declination of the metatarsal head. Two investigators (MP, RM) separately performed all measurements for each lateral translation (1–3–5 mm) and their means where thereafter calculated and registered as the X2 value. Difference between the two measures (X2–X1) for each lateral displacement and angulation corresponded to the declination of the metatarsal head produced by the osteotomy.

Finally, twenty-two specimens were evaluated and registered: 3 ft were operated on using an osteotomy angle parallel to the plantar cortex of the first metatarsal (0°), 6 ft with an angle of 10°, 5 ft with an angle of 20°, 5 ft with an angle of 30° and 3 ft with an angle of 40°.

### 2.3. Statistics

One-way analysis of variance (ANOVA) model was utilized to estimate declination of the first metatarsal head. For this purpose, declination was set as the dependent variable, while displacement (mm) and angulation (degrees) were determined to behave as fixed effect factors. To evaluate independency of effect factors, interaction between them is also reported. Results are expressed as declination mean and 95% confidence interval. Post hoc analysis was performed using LSD correction to account for differences between displacement and angulation.

An independent statistician performed all statistic analyses using SPSS (IBM) for Windows, v. 20.0, and using a Type I bilateral error of 5%.

## 3. Results

Twenty-two specimens were included in the study. These corresponded to fourteen right and eight left feet. Estimated declination for each measurement is reported in Table 1.

A significant increment in mean declination of the first metatarsal head was observed when increasing angulation used to perform the oblique trace of the osteotomy increased ($p < 0.001$). Furthermore, mean declination increased with lateral translation of the osteotomy ($p < 0.001$) and a significant declination of the first metatarsal head was documented for amount of displacement (1, 3 and 5 mm). However, the interaction between angulation and lateral translation did not achieve statistical significance ($p = 0.597$) (Table 1).

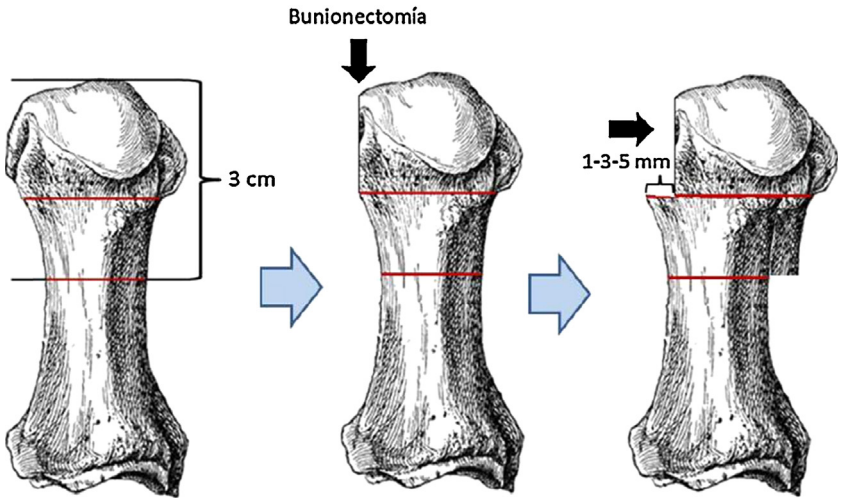



**Fig. 5.** Osteotomy design in the frontal plane and lateral translation.

When comparing the different angulations of the oblique limb of the osteotomy, a correlation was observed between 0°, 10°–20° and 30°–40° groups.

Mean declination of the metatarsal head was −0.6 mm (CI95%: −1.07; −0.13), −1.35 mm (CI95%: −1.89; −0.81) and −1.61 mm (CI95%: −2.24; −0.98 when comparing performance of the osteotomy at an angulation of 0°–20° ($p = 0.012$), 0°–30° ($p < 0.001$) and 0°–40° ($p < 0.001$), respectively. This effect was not observed with 0°–10° comparison ($p = 0.092$).

Mean declination of the metatarsal head was −0.93 mm CI95% (−1.40; −0.47) and −1.19 mm CI95% (−1.77; −0.62) when comparing performance of the osteotomy at an angulation of 10°–30° ($p < 0.001$) and 10–40° ($p < 0.001$). This effect was not observed with 10°–20° comparison ($p = 0.348$).

Thereafter, when comparing the osteotomy between 20°–30° and 20°–40° a significant declination of the metatarsal head of -0.75 mmCI95% (−1.20; −0.30), $p = 0.001$ and −1.01 mm CI95% (−1.57; −0.45), $p < 0.001$ was, respectively, demonstrated. However, this did not occur when the comparison between performances at 30° and 40° was examined (Table 2).

For the aforementioned interactions, three differentiated groups were identified in which intragroup declination of the metatarsal head was statistically comparable. These groups corresponded to 0°, 10–20° and 30–40°.

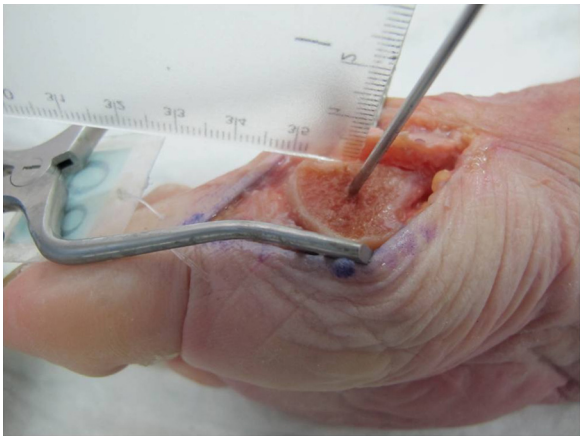


**Fig. 6.** Intraoperative measurement of lateral translation.

The metatarsal sesamoid articulation was breached in all the specimens in which the oblique limb of the osteotomy was performed using an angulation of 40° (Fig. 7).

## 4. Discussion

Although unique or repetitive trauma may have a role producing hallux rigidus, definitive mechanism remains elusive [13]. First ray elevation, described to be pathologic and a precursor of this condition by Lambrinudi [14], appears to be a consequence of biomechanical malfunctioning of the articulation rather than its cause [15]. This elevation can be static or dynamic, mainly due to posterior tibial tendon dysfunction, peroneal palsy or pain. Nevertheless, progression of the disease often increases this elevation [13].

The objective of surgical management of hallux rigidus at Coughlin stage 0, 1 and 2 is to obtain symptom relief, improve function and address pathology at the apex of the deformity [1]. Ronconi et al. [9] demonstrated 84% of good and excellent results when a distal metatarsal osteotomy was performed to remodel the metatarsal head by modifying the rotation axis and decompressing the joint. Using this approach, they reported a net increase of 23° of range of motion. Other authors have reproduced similar clinical outcomes as well [3,15,16].

Currently, declination of the metatarsal head in the sagittal plane is obtained by distal metatarsal osteotomies through a relative shortening of the metatarsal length. Moreover, periarticular osteotomies have been discouraged in the treatment of hallux rigidus due to a higher risk of revision surgery and transfer

**Table 1**
Variable interaction model: estimated first metatarsal head declination according to lateral displacement and inclination angle.

| | Estimated average | IC95% | *p*-Value | Interaction, *p*-Value (*) |
|---|---|---|---|---|
| Displacement (mm) | | | <0.001 | 0.597 |
| 1 | 0.5 | (0.3; 0.8) | | |
| 3 | 1.1 | (0.8; 1.3) | | |
| 5 | 1.8 | (1.5; 2.1) | | |
| Inclination angle | | | <0.001 | |
| 0° | 0.3 | (−0.1; 0.7) | | |
| 10° | 0.8 | (0.5; 1.0) | | |
| 20° | 0.9 | (0.7; 1.2) | | |
| 30° | 1.7 | (1.3; 2.1) | | |
| 40° | 1.9 | (1.4; 2.4) | | |

* From the model with interaction.

**Table 2**
Estimated declination of the metatarsal head in relation to osteotomy angle and lateral displacement.

| ANG | 95% Wld confidence Intervl | | Men |
|---|---|---|---|
| | Lower | Upper | |
| 0° | −0.059 | 0.725 | 0.333 |
| 10° | 0.464 | 1.036 | 0.75 |
| 20° | 0.679 | 1.188 | 0.933 |
| 30° | 1.314 | 2.053 | 1.683 |
| 40° | 1.447 | 2.442 | 1.944 |
| 1 mm | 0.275 | 0.765 | 0.52 |
| 3 mm | 0.798 | 1.308 | 1.053 |
| 5 mm | 1.496 | 2.132 | 1.814 |

metatarsalgia [16]. However, this recommendation was based on a revision of four different osteotomies that achieve joint decompression and plantarflexion of the metatarsal head by means of metatarsal shortening. The result of the metatarsal shortening can lead to, transfer metatarsalgia.

Considering these problems, we believe this modification of a previously described osteotomy results in plantar flexion of the first ray while limiting shortening of the metatarsal length. Therefore, the simple oblique trace from the Weil-Barouk osteotomy [8] is combined with the Ronconi [9] concept of using the inclination in the horizontal plane to increase head declination. In addition, a second transverse limb has been added to control rotation and limit metatarsal shortening. This transverse limb is a key point that differentiates this modification from previously described distal metatarsal osteotomies ensuring that metatarsal length is preserved or minimally altered [10].

The objective of this osteotomy is a tridimensional reconstruction of the first metatarsal. Declination of the head is achieved by means of lateral translation and varying the inclination angle of the osteotomy in the transverse plane. This aspect is a crucial consideration when other osteotomies are being contemplated and may appear to produce a similar result. On the other hand, adding a dorsal cut should diminish transfer metatarsalgia risk by limiting the shortening required to produce head declination and therefore, prevent second metatarsal overload. Additionally, we believe that this contributes to stability of the construct and precludes inadvertent proximal displacement of the metatarsal head. Moreover, in an index plus forefoot, when first ray shortening may be beneficial, resecting a fragment of the same width of the desired shortening can be performed.

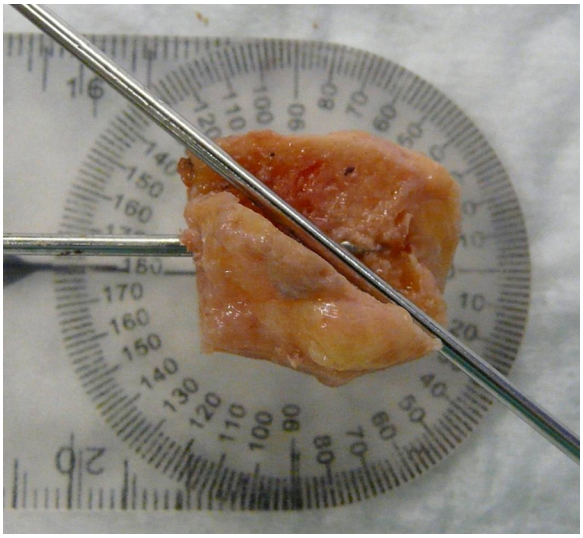


**Fig. 7.** Metatarsal head view after the osteotomy was performed at 40° of inclination angle labeled where the metatarsal sesamoid articulation was breached.

We demonstrated that progressively increasing the cutting-angle of the oblique limb of the osteotomy increased first metatarsal head declination ($p < 0.001$). This observation was also observed when lateral translation of the metatarsal head was performed ($p < 0.001$). The total estimated declination was 1.5 to 2.1 mm at maximum displacement (5 mm). Notably, we did not observe an interaction between both variables. This means that to obtain the desired effect, independent adjustment of angulation or displacement can be sufficient, without a modifying effect from the non-adjusted variable. This interaction provides an invaluable tool when preoperatively planning, allowing adjusting the osteotomy on patients based on individual forefoot morphologies.

Presence of three statistically distinctive groups in regards to angulation of the oblique limb of the osteotomy is noteworthy. Those provide the surgeon with a safe margin to execute the osteotomy and avoid using complex and otherwise expensive surgical instruments to determine the precise angulation of the osteotomy. Accordingly, the osteotomy needs to be performed at 0° if no declination of the metatarsal head is desired (CI95% −0.1–0.7 mm); between 10 and 20° if around 1 mm is planned (CI95% 0.5–1.2 mm) or between 30 and 40° if 1.3 and 2.4 mm are needed.

Careful preoperative planning cannot be overemphasized: if only metatarsal head declination is pursued and limited metatarsal shortening desired, the osteotomy cut should be performed at a lower angle (20 or 30°) with minimal translation. However, if a concomitant hallux valgus correction is attempted and more translation will be needed to reduce the intermetatarsal angle, the osteotomy can be performed at a lower angle to obtain a similar head declination effect as well. A higher cutting angle should only be considered in cases with a long first metatarsal in whom shortening though the dorsal limb cut is planned and hence, shortening will occur without any substantial declination.

Young foot and ankle surgeons must be aware of the potential elevation risk and transfer metatarsalgia when performing vertical osteotomies. The longitudinal limb of the osteotomy should be parallel to the plantar aspect of the first metatarsal shaft (referred here as 0°) if no first metatarsal head declination is desired. To ensure metatarsal plantar declination when translating the osteotomy, consideration should be given to place a Kirschner wire with the anticipated plantar lateral angulation. The latter will guide the surgeon during osteotomy performance and will avoid dorsal lateral angulation, which will produce the opposite effect to the first metatarsal head, with the subsequent transfer metatarsalgia risk.

Espinosa et al. [17] demonstrated a significant 5.2 mm elevation of the first metatarsal in patients with hallux rigidus compared with hallux valgus and controls in a 295 ft study. In these latter two groups of patients, the position of the first metatarsal was at 2.8 and 2.6 mm of elevation from the second metatarsal, respectively. Theoretically, declination of the first metatarsal head into the "normal" (control) range is desirable. Descending the metatarsal head by 2 to 3 mm should eliminate the mechanical restrictions of dorsiflexion of the hallux and hence improve joint biomechanics. Based on our results,, angulating the oblique limb of the osteotomy in 30 or 40° and displacing the plantar fragment laterally by 5 mm can accomplish this.

Clinically, we believe that this scenario may be advantageous. In addition to the rigid component of the deformity, patients may present mild increase of their 1–2 intermetatarsal angle that is

correctable through lateral displacement. We found that performing the osteotomy at 30 or 40° is equivalent in terms of net declination. Caution is warranted when attempting to perform the osteotomy at 40° as stability of the plantar fragment may be compromised and metatarsal sesamoid joint violated. The cartilage of this joint was disrupted in each tested specimen when a 40° osteotomy was used. Therefore, we believe that this osteotomy should be performed at a maximum inclination of 30° in the transverse plane.

To the best of our knowledge, this study is the first to quantify the effect of a first metatarsal osteotomy to treat hallux rigidus in a cadaveric setting. We were unable to find any previous cadaveric investigation to compare their outcomes against our findings.

This study has several limitations. First, quality of cadaveric bone differs greatly from the clinical situation and thus, potential collapse between fragments may underestimate the real power of the osteotomy. Additionally, we did not measure length of the first metatarsal and therefore objective measurement of shortening cannot be provided. Nevertheless, we did not resect more bone than inherently resected by the mini saw when bone is cut. Consequently, we do not expect significant metatarsal shortening. Currently, a clinical and radiological protocol is being conducted to assess for effective first metatarsal head declination and shortening when this osteotomy is performed.

## 5. Conclusions

Transverse angulation of the osteotomy and lateral displacement are independent factors affecting first metatarsal head declination. First metatarsal head declination may be optimized by selecting the desired transverse angulation on a patient-to-patient basis. No interaction was found between translation and angulation, hence selecting the desired angulation should not affect the expected declination.

## Conflict of interest statement

We declare no conflict of interests.

## Acknowledgments

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