Fourth-Generation Minimally Invasive Hallux Valgus Surgery With Metaphyseal Extra-Articular Transverse and Akin Osteotomy (META): 12 Month Clinical and Radiologic Results

Thomas L. Lewis, MBChB, BSc, MRCS, MFSTEd1, Benjamin Lau, BSc, MRCS1, Yousif Alkhalfan, MBCh, BAO, MRCS2, Samuel Trowbridge, MBBS, MRCS1, David Gordon, MBChB, MRCS, MD, FRCS(Tr & Orth)3, Joel Vernois, MD4, Peter Lam, MBBS, FRACS5, and Robbie Ray, MBChB, ChM(T&O), FRCSed(Tr & Orth), FEBOT1

Abstract

Background: Fourth-generation minimally invasive surgery (MIS) includes the multiplanar rotational deformity correction achieved through manipulation of an extra-articular distal first metatarsal osteotomy that is held with rigid fixation using 2 fully threaded screws, of which one must be bicortical to provide rotational and biomechanical stability. The aim of this study is to report the clinical and radiologic outcomes of an evolved fourth-generation MIS hallux valgus technique.

Methods: A prospective single-surgeon series of consecutive patients undergoing fourth-generation MIS was performed using a distal transverse osteotomy with a minimum 12-month follow-up. The primary outcome was the Manchester-Oxford Foot Questionnaire (MOXFQ), a validated clinical patient-reported outcome measure (PROM). Secondary outcomes included radiographic deformity correction, clinical assessment, and EuroQol-5D-5L PROMs.

Results: Between September 2019 and June 2021, 50 feet underwent fourth-generation MIS. The mean age was 55.8 ± 15.3 years with a mean follow-up of 1.4 years. Preoperative and minimum 12-month primary outcome data were available for 100% of feet. There was a significant improvement in all MOXFQ domain scores, with the index domain improving from 53.4 to 13.1 (P < .001). There was a significant improvement (P < .001) in hallux valgus angle (32.7 to 7.9 degrees), intermetatarsal angle (14.0 to 4.2 degrees) and distal metatarsal articular angle (18.5 to 5.6 degrees). There was a significant improvement in general health-related quality of life EQ-5D-5L index and EQ-VAS scores (P < .05).

Conclusion: The fourth-generation MIS technique is a safe and effective approach to hallux valgus deformity correction with significant improvement in clinical and radiographic outcomes.

Level of Evidence: Level IV, prospective case series.

Keywords: minimally invasive surgery, MOXFQ, hallux valgus, patient-reported outcome measure, EQ-5D, PROM, MICA, PECA, forefoot surgery, META

Introduction

Minimally invasive or percutaneous hallux valgus surgery (MIS) was first described in 199159 and has evolved through 3 distinct generations13,51 with advances in technology, instrumentation, and understanding of biomechanics. First-generation MIS techniques do not use internal fixation, whereas second-generation techniques relied on Kirschner (K)-wires for stability. Third-generation MIS techniques used screw fixation and a distal chevron osteotomy to provide additional stability enabling early weightbearing and range of motion. Studies of third-generation MIS techniques reported significant improvement in clinical and radiologic outcomes, with a low radiographic recurrence rate.5,21,24,28,31-33,35,42,45,50 Comparative systematic reviews of open and percutaneous techniques suggest no significant difference in radiographic correction, pain, and function at 6 months.15,23 Recently, there has been increased interest and research on third-generation MIS techniques and the applicability of
these techniques to different types of deformity. Studies have suggested the radiographic deformity correction that can be achieved using certain MIS techniques in severe deformities is potentially greater than reported in a range of open techniques with similar complication rates.

Comparing third-generation MIS techniques is challenging given that there are a broad spectrum of techniques used with different osteotomies, different zones of fixation (eg, percutaneous intra-articular chevron osteotomy [PEICO] vs minimally invasive chevron and Akin osteotomy [MICA]), number of screws, and different inclusion/exclusion criteria, which are all considered “third-generation.” Even when procedures are described using specific acronyms, surgeons cannot agree on what constitutes the important aspects of the procedure. This makes drawing comparisons between different techniques difficult. Previous iterations of MIS surgery primarily aim to re-create an open procedure using MIS techniques, which may also limit the range of deformities that can be managed. Factors such as rotational correction, technique and stability of an osteotomy, complications, and clinical outcomes are often heterogeneous or poorly reported in the literature. Defining a new “fourth-generation” that incorporates key surgical steps will help surgeons make appropriate comparisons between different minimally invasive techniques. These key surgical steps revolve around deformity correction including pronation, strength of fixation, and steps to reduce recurrence.

Fourth-generation MIS surgery aims to correct all severities of coronal/sagittal plane deformity and rotational deformities of the metatarsal articulation. It can be defined as a distal extra-articular metaphyseal unstable osteotomy, combined with an active 3-dimensional reduction maneuver to correct all planes of deformity, held with rigid stable bicortical fixation using 2 screws in order to allow early weightbearing and rehabilitation.

**Objectives**

The primary aim was to report the clinical and radiographic results of consecutive patients undergoing fourth-generation MIS for hallux valgus deformity using a validated patient-reported outcome measure (PROM).

**Methods**

**Minimally Invasive Extra-articular Transverse and Akin Osteotomy Technique**

The minimally invasive extra-articular transverse and akin osteotomy (META) surgical technique (Figure 1) is an evolution of the third-generation technique developed by Dr Joel Vernois.

A lateral release is not performed at the beginning of the procedure. This is a key step of the fourth-generation technique so that there is no loss of lateral soft tissue tension needed for manual correction of the 3-dimensional deformity through the distal first metatarsal osteotomy.

An extra-articular distal metaphyseal osteotomy is made at the level of the first metatarsal neck. Although similar technical results can be achieved with a short chevron osteotomy, the senior author always uses a transverse osteotomy. An extracapsular osteotomy is used as it enables increased translation and rotational correction as the mobility of the capital fragment will not be limited by capsular tightness (Figure 2).

A number of steps are taken to reduce the risk of iatrogenic thermal injury. This includes use of an irrigated high-torque, low-speed handpiece, regular clearing of bone debris from the burr flutes, and minimizing burr time. The senior author uses a tourniquet as a preference; however, we recognize that some surgeons avoid using a tourniquet to help further reduce the risk of thermal injury. The thickness of the burr used for the metatarsal osteotomy is 2.2 mm, and to compensate for the shortening caused by burr-associated bone loss, the burr is angled proximal to distal, usually 10 degrees to a line perpendicular to the second metatarsal shaft.

Another key concept of the fourth-generation technique is that the osteotomy itself should be “unstable” to allow for maximal 3-dimensional correction of the metatarsal head in conjunction with the intact lateral structures. Although a chevron osteotomy is potentially more stable, this configuration hampers rotational correction and risks poor fixation and early positional failure in the postoperative period because of lateral wall fracture or screw loss of purchase.

A 3-dimensional correction of all deformities should now be performed. An intramedullary reduction tool is used to reduce the first metatarsal head closer to the second metatarsal while simultaneously tensioning the first tarsometatarsal (TMT) joint, thereby reducing the potential for instability here. The nondominant hand is then used to supinate the great
Lewis et al

toe, correcting rotation of the first metatarsal head through ligamentotaxis to an anatomical rectus position with image guidance used to ensure that sesamoid rotation is corrected. The dominant hand holds the metatarsal head throughout ensuring no dorsoplantar deformity. Reduction can be achieved even in cases of severe deformity where tension on the lateral tissues can aid reduction (Figures 1, 2, and 4) highlighting the importance of leaving the lateral release until the metatarsal is fixed in the correct position.

The next step is placement of a guidewire into the lateral third of the head to maintain the reduction while rigid fixation is achieved with parallel cannulated fully threaded screws, one of which must be bicortical.2,34 The wire must be of adequate stiffness to allow for lateral wall purchase and perforation without intramedullary slippage. In this series the author used a 1.6-mm wire (Figure 2C and 2D) which was then converted to a 1.2-mm wire after drilling and prior to screw insertion (Figure 2E) due to the internal diameter of the screw. For this reason, the reduction is held during the insertion of the first screw (Figure 2F). This is technically much easier when a transverse osteotomy is used as there is more bone around the lateral cortex exit site than at the apex of a chevron osteotomy, thus reducing the risk of lateral wall fracture (Figure 3).

The medial ledge and any prominent medial exostosis were excised. We recommend routine medial eminence resection following the osteotomy as in our experience, resecting the eminence prior to correction, may lead to increased difficulty, reducing the deformity. A percutaneous Akin osteotomy was always performed following the metatarsal osteotomy. A first metatarsophalangeal lateral release (involving division of the lateral sesamoid-phalangeal ligament) was only performed if required to fully correct the hallux valgus deformity and restore first metatarsophalangeal joint congruity.

Patients are allowed to mobilize full weightbearing in a flat surgical sandal from the day of procedure with conversion to soft trainers with a wide toe box at 2 weeks. Noncontact exercises and jogging can be restarted at 4 and 6 weeks following surgery, respectively.

**Study Design**

Prospective observational study of consecutive patients undergoing fourth-generation MIS hallux valgus deformity correction. The study was designed prior to enrollment of the first patient and reported in line with the STROBE guidelines for observational studies.56

---

**Figure 1.** Fourth-generation minimally invasive surgery using a transverse osteotomy in a case of severe hallux valgus deformity. Radiographs show preoperative, 6 months and 12 months following surgery. Correction of the hallux valgus angle, intermetatarsal angle, distal metatarsal articular angle, sesamoid position, and increase in proximal intermetatarsal angle of the first tarsometatarsal joint can be seen.
Study Setting

All operations were performed by a single surgeon (R.R.) in 2 hospitals in London, United Kingdom. This surgeon was fellowship trained specifically in minimally invasive techniques, and this series includes all cases from the surgeons’ learning curve.

Participants

Consecutive patients aged 16 years and older, who underwent primary correction of hallux valgus were included. Patients were all counseled regarding conservative treatments for hallux valgus deformity including shoe wear advice, toe sleeves, and spacers prior to being offered...
surgery. Patients of all radiologic severities and congruent and incongruent deformities were included. Patients with first TMT joint instability or a diagnosis of generalized hypermobility were included. Patients who underwent additional forefoot procedures, for example, hammer toe corrections, distal metaphyseal, and metatarsal osteotomy, were included. The only exclusion criterion was symptomatic osteoarthritis of the first TMT joint in the presence of hallux valgus deformity or cases of revision hallux valgus surgery.
Data Sources/Collection
Each patient prospectively completed preoperative PROMs, which were stored in a national online registry on the day of surgery. Patients completed follow-up PROMs and clinical and radiologic assessment at routine time points following surgery (preoperative, 6 weeks, 3 months, 6 months, and 12 months).

Variables, Outcome Measures, and Study Endpoint
The primary outcome was a validated foot and ankle PROM, the Manchester-Oxford Foot Questionnaire (MOXFQ), which was assessed at a minimum of 1 year following fourth-generation MIS. The MOXFQ score is a validated PROM consisting of 3 separate domains (pain [P], walking and standing [W/S], and social interaction [SI]) with an overall summary index score. The score for each domain ranges from 0-100, 0 best possible score with a change in score of 16.8 recognized as the minimum clinically important difference (MCID) for the index domain (MCID of 16, 12, and 24 for W/S, P, and SI, respectively). Secondary outcomes included validated general health-related quality of life PROMs, radiographic and visual deformity correction. Secondary PROMs included the EuroQol EQ-5D-5L, EQ-5D-5L visual analog scale (EQ-V AS), and pain visual analog scale (VAS-Pain).

The intermetatarsal angle (IMA), distal metatarsal articular angle (DMAA), and hallux valgus angle (HVA) were measured according to the American Orthopaedic Foot & Ankle Society technique and categorized with regard to deformity severity. Lateral sesamoid position was categorized according to Agrawal et al. The shape of the first metatarsal (MT) head, the “round sign” was assessed according to Okuda et al. Each patient was assessed pre-surgery and 6 weeks postsurgery using the Manchester visual scale in the manner described by Menz and Munteanu. (Figure 4). Recurrence was defined as HVA >15 degrees on weightbearing radiographs assessed 12 months following surgery.

The intermetatarsal angle between the proximal fragment of the osteotomy and the second ray (“proximal IMA”) as described by Nunes et al was measured on postoperative radiographs to assess if there was an increase in the proximal IMA following surgery. Deformity correction was assessed in terms of “percentage head shift” (PHS) as shown and defined in Figure 5. The 6-week postoperative weightbearing radiograph was used for the PHS, and the last radiograph was used for the assessment of radiographic deformity correction.

Complications identified by either the patient or surgeon in outpatient clinics were prospectively recorded at the point of diagnosis and categorized using the Adapted Clavien-Dindo-Sink complication classification for hallux valgus surgery.

Bias
We attempted to address potential sources of bias within the study design. Radiographic analysis was carried out by members of the study team masked to clinical PROM outcomes. We purposefully minimized exclusion criteria and included consecutive patients in order to reduce selection bias. Data were collected prospectively, minimizing recall bias.

Statistical Analysis
The preoperative clinical data were tested for normality using the Shapiro-Wilk test, which indicated the data were from a normal distribution. The paired and independent t test for parametric data was used for continuous outcomes and descriptive statistics used for categorical data. All analyses were performed with Python SciPy package. The cohort of included participants was divided in two based on whether or not additional lesser toe procedures were performed concurrently with META. Subgroup analysis was performed to identify if these additional procedures had an impact on clinical outcomes. Statistical significance was defined as P <.05.

Ethical Approval and Funding
This study was registered as a local service evaluation project for analysis of routinely collected data including...
Lewis et al

prospectively collected PROMs and radiographs. Informed consent was obtained from all participants. There was no funding to support this study.

**Results**

**Patient Demographics**

Between September 2019 and June 2021, 44 consecutive patients (38 female, 6 male) comprising 47 feet underwent fourth-generation MIS hallux valgus deformity correction. The mean (± SD) age was 55.4±15.7 years (range 24.8-86.3). The mean clinical follow-up was 1.3±0.4 years (range 1.0-2.3). The mean patient body mass index was 26.3±4.2. Figure 6 shows a flowchart demonstrating the participant pathway.

**Patient-Reported Outcome Measures**

There was a statistically significant improvement in all MOXFQ domains (P < .05) as seen in Table 1 and Figure 7. PROMs were available for all 47 feet (100%). There was a similar significant improvement in VAS-Pain and general health-related quality of life PROMs (P < .05).

**Additional Procedures**

Forty percent of patients underwent isolated fourth-generation MIS hallux valgus (HV) deformity correction. The remaining 60% of patients underwent additional procedures at the same time as primary fourth-generation MIS. This included 23 lesser toe proximal and distal interphalangeal joint deformity corrections, 3 bunionette corrections, 1 K-wire fixation for dislocated second toe, and 1 case of lesser metatarsal distal osteotomies for metatarsalgia in rheumatoid arthritis (note some of these procedures were combined). There was no statistically significant difference in pre- or postoperative clinical or radiologic outcome measures, as demonstrated in Table 2.

**Radiographic Outcomes**

Pre- and postoperative weightbearing radiographs were available for all 47 feet; however, only 42 of these met the 12-month inclusion criteria for analysis (89.4%) (Figure 6). The mean radiographic follow-up was 1.53±0.51 years. Table 3 shows significant improvement in radiographic deformity correction in all radiographic parameters (HVA, IMA, and DMAA) (P < .05).

The mean percentage head shift was 69.2%±22.6% (range 5.0-100.0). The mean first metatarsal shortening was 1.3±3.3 mm. The mean proximal IMA was 20.3±4.7 degrees, which was a statistically significant increase of 6.3 degrees (P < .05).
There were 9 complications as seen in Table 4. There was 1 recurrence of deformity, with HVA increasing from 11 to 17 degrees (Figure 8). The recurrence occurred between the 6-week and 6-month radiographs. Despite the recurrence, the patient was very satisfied (MOXFQ index score of 0 at 2 years), with no radiographic progression of deformity between 6 months and 2 years following surgery.

Discussion

This article describes the clinical and radiographic outcomes of patients treated with fourth-generation evolution of the MIS hallux valgus technique from third-generation techniques. There was a significant improvement between preoperation and 12 months postoperation in all clinical domains of the MOXFQ, with the mean improvement in each domain greater than the MCID, demonstrating the clinical efficacy of META. There was also a significant improvement in radiographic deformity correction and health-related quality of life. This study has reported radiographic and clinical outcomes not previously reported in the third-generation literature, such as sesamoid position, round sign, proximal IMA, Manchester visual foot score, and percentage head shift, which will allow comparisons with future studies to be performed.

Fourth-generation MIS is the multiplanar rotational deformity correction that can be achieved by manipulating an “unstable” extra-articular distal osteotomy held with rigid fixation using 2 screws, of which the first must be bicortical to provide rotational and biomechanical stability. One cadaveric biomechanical study demonstrated no significant difference in ultimate load, yield load, and stiffness between MIS transverse and chevron osteotomy constructs; however, it did observe a trend toward increased strength in the transverse osteotomy cohort. Nevertheless, it is important to note that this biomechanical study was limited by the technique used for the comparison in which not all cadavers had at least 1 screw placed bicortical prior to entering the capital fragment, making a true comparison to our surgical technique difficult. We believe there is a risk that a plantar screw combined with a chevron osteotomy may have limited fixation stability because of limited bone stock, risking lateral wall fracture, osteotomy collapse, and postoperative loss of...
**Table 2.** Comparative Table of Clinical and Radiographic Outcomes Based on Whether Additional Procedures Were Performed Alongside Fourth-Generation META.

<table>
<thead>
<tr>
<th>Isolated META</th>
<th>META + Additional Procedures</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (%) of feet</td>
<td>19 (40.4)</td>
<td>28 (59.6)</td>
</tr>
<tr>
<td>Preoperative IMA/HVA, degrees, mean ± SD</td>
<td>49.4 ± 12.6</td>
<td>59.6 ± 16.5</td>
</tr>
<tr>
<td>IMA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVA</td>
<td>14.1 ± 3.8</td>
<td>13.7 ± 3.6</td>
</tr>
<tr>
<td>Postoperative IMA/HVA, degrees, mean ± SD</td>
<td>30.9 ± 8.0</td>
<td>33.8 ± 9.2</td>
</tr>
<tr>
<td>IMA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVA</td>
<td>3.8 ± 2.4</td>
<td>4.3 ± 2.8</td>
</tr>
<tr>
<td></td>
<td>6.3 ± 3.9</td>
<td>8.7 ± 5.4</td>
</tr>
<tr>
<td>Preoperative MOXFQ domain score, mean ± SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index</td>
<td>57.9 ± 23.2</td>
<td>50.3 ± 19.1</td>
</tr>
<tr>
<td>Walking/standing</td>
<td>58.1 ± 27.9</td>
<td>50.8 ± 21.0</td>
</tr>
<tr>
<td>Pain</td>
<td>60.8 ± 23.5</td>
<td>48.9 ± 21.7</td>
</tr>
<tr>
<td>Social interaction</td>
<td>54.1 ± 24.8</td>
<td>50.8 ± 21.0</td>
</tr>
<tr>
<td>12-mo postoperative MOXFQ domain score, mean ± SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index</td>
<td>15.7 ± 22.9</td>
<td>11.3 ± 12.8</td>
</tr>
<tr>
<td>Walking/standing</td>
<td>17.8 ± 28.1</td>
<td>10.6 ± 13.0</td>
</tr>
<tr>
<td>Pain</td>
<td>18.4 ± 26.2</td>
<td>12.7 ± 15.4</td>
</tr>
<tr>
<td>Social interaction</td>
<td>8.5 ± 14.5</td>
<td>10.8 ± 16.0</td>
</tr>
</tbody>
</table>

Abbreviations: HVA, hallux valgus angle; IMA, intermetatarsal angle; META, minimally invasive extra-articular transverse and akin osteotomy; MOXFQ, Manchester-Oxford Foot Questionnaire.

**Table 3.** Pre- and Postoperative Radiographic Deformity Correction Assessed on Weightbearing Radiographs Following Fourth-Generation Minimally Invasive Surgery.

<table>
<thead>
<tr>
<th>Angle</th>
<th>Preoperative</th>
<th>Final Follow-up</th>
<th>Change (Preoperative to Final Follow-up)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMA (degrees)</td>
<td>14.0 ± 3.6</td>
<td>4.2 ± 2.5</td>
<td>−9.8 ± 3.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>HVA (degrees)</td>
<td>32.7 ± 8.8</td>
<td>7.9 ± 5.0</td>
<td>−24.8 ± 8.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>DMAA (degrees)</td>
<td>18.5 ± 6.4</td>
<td>5.6 ± 3.5</td>
<td>−12.9 ± 6.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Manchester Score (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.0</td>
<td>83.3</td>
<td>+83.3</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Mild</td>
<td>11.9</td>
<td>16.7</td>
<td>+4.8</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>50.0</td>
<td>0.0</td>
<td>−50.0</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>38.1</td>
<td>0.0</td>
<td>−38.1</td>
<td></td>
</tr>
<tr>
<td>Sesamoid position (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>2.4</td>
<td>38.1</td>
<td>+35.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Mild</td>
<td>14.3</td>
<td>35.7</td>
<td>+21.4</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>26.2</td>
<td>26.2</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>57.1</td>
<td>0.0</td>
<td>−57.1</td>
<td></td>
</tr>
<tr>
<td>Round sign (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angular</td>
<td>11.9</td>
<td>90.5</td>
<td>+78.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Intermediate</td>
<td>21.4</td>
<td>9.5</td>
<td>−11.9</td>
<td></td>
</tr>
<tr>
<td>Round</td>
<td>66.7</td>
<td>0.0</td>
<td>−66.7</td>
<td></td>
</tr>
<tr>
<td>Percentage congruent joints (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall deformity (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.0</td>
<td>92.9</td>
<td>+92.9</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Mild</td>
<td>9.5</td>
<td>7.1</td>
<td>−2.4</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>64.3</td>
<td>0.0</td>
<td>−64.3</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>26.2</td>
<td>0.0</td>
<td>−26.2</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: DMAA, distal metatarsal articular angle; HVA, hallux valgus angle; IMA, intermetatarsal angle.

*Mild deformity: HVA (15°-20°) and/or IMA (9°-14°); moderate deformity: HVA (20°-40°) and/or IMA (14°-20°); severe deformity: HVA (≥40°) and/or IMA (≥20°).
position. Conversely, we believe, if a screw is placed in the same trajectory with a transverse osteotomy, there is ample bone stock for fixation stability although we recognize this should be tested in further biomechanical cadaveric studies. Recent studies have confirmed that there is considerable rotation of the first metatarsal in hallux valgus deformity, which should be corrected as part of the overall deformity correction.8,41,49,57,58 A transverse osteotomy potentially allows better rotational control and correction of the head compared to a chevron. As a transverse osteotomy is inherently unstable, it does have to be controlled with a reduction maneuver during fixation; otherwise, there is a risk of mal-union in the sagittal plane. With a transverse osteotomy, there is also a concern for the plantar blood supply of the capital fragment. We had no evidence of avascular necrosis or nonunion in this series but recognize this should be monitored and reported in large, long-term series.

The improvement in clinical PROMs and radiographic deformity correction in this series is comparable to series of third-generation MIS HV techniques using a chevron osteotomy.5,21,33,35,39 The preoperative MOXFQ domain scores in our study are higher than reported in other series, which likely reflects differences in the patient population. Despite this, the mean clinical PROMs at 12 months following surgery are comparable to other studies as shown in Table 5. It was not possible to draw direct comparisons to studies using either the Lapidus or scarf/Akin osteotomy technique, as we were unable to identify any studies using the validated MOXFQ PROM.

The radiographic deformity correction achieved in this series is comparable to other series of MIS HV techniques. We found that there was minimal recurrence of HV deformity, which has been reported in other studies and believe this is due to the combination of a bony correction combined with “medially locking out” the TMT joint to prevent any further increase in the IMA.43 The proximal IMA in this series increased by 6.3 degrees, which is comparable to Nunes et al43 who found an increase of 4.8 degrees following MIS HV surgery. The final proximal IMA in this study (20.3 degrees) was also comparable to their study, which found a proximal IMA of 19.0 degrees. Biomechanical and clinical studies investigating the varus angular limit of the first TMT joint may help improve understanding of the factors leading to recurrence or address concerns regarding development of instability or arthritis in this joint following MIS HV surgery.

We found a mean shortening of 1.3 mm at final follow-up and believe it is unlikely that this small amount of shortening will predispose to transfer lesions seen in previous generations of MIS hallux valgus correction as shortening of up to 8 mm was regarded as acceptable in Turnbull and Grange’s series.52 This study reported on significant improvement in lateral sesamoid position and round sign, which is not

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of feet</th>
<th>Follow-up (mo)</th>
<th>Pain</th>
<th>Walking/Standing</th>
<th>Social Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>47</td>
<td>16</td>
<td>53.7 to 15.0</td>
<td>53.9 to 13.6</td>
<td>52.1 to 9.9</td>
</tr>
<tr>
<td>Hernández-Castillejo et al (2022)10</td>
<td>32</td>
<td>18</td>
<td>68.8 to 9.5</td>
<td>61.6 to 14.8</td>
<td>51.0 to 10.7</td>
</tr>
<tr>
<td>Lewis et al (2023)8</td>
<td>77</td>
<td>69</td>
<td>Unknown to 12.3</td>
<td>Unknown to 8.0</td>
<td>Unknown to 12.6</td>
</tr>
<tr>
<td>Lewis et al (2022)22</td>
<td>202</td>
<td>26</td>
<td>42.8 to 8.9</td>
<td>36.5 to 6.0</td>
<td>45.0 to 5.2</td>
</tr>
<tr>
<td>Lewis et al (2022)31</td>
<td>106</td>
<td>29</td>
<td>39.2 to 7.5</td>
<td>38.2 to 5.9</td>
<td>48.6 to 5.5</td>
</tr>
<tr>
<td>Patnaik et al (2022)46</td>
<td>27</td>
<td>26</td>
<td>Index score only reported 64.6 to 11.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Del Vecchio et al (2021)14</td>
<td>114</td>
<td>24</td>
<td>Index score only reported 40.0 to 5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guo et al (2021)16</td>
<td>48</td>
<td>24</td>
<td>51.6 to 15.8</td>
<td>50.3 to 13.5</td>
<td>56.9 to 13.3</td>
</tr>
<tr>
<td>Lewis et al (2021)33</td>
<td>292</td>
<td>26</td>
<td>44.5 to 9.4</td>
<td>38.7 to 6.5</td>
<td>48.0 to 6.6</td>
</tr>
<tr>
<td>Lewis et al (2021)35</td>
<td>51</td>
<td>37</td>
<td>Unknown to 18.9</td>
<td>Unknown to 14.7</td>
<td>Unknown to 11.2</td>
</tr>
<tr>
<td>Holme et al (2020)21</td>
<td>40</td>
<td>12</td>
<td>65.6 to 10.9</td>
<td>56.3 to 8.7</td>
<td>53.4 to 9.7</td>
</tr>
<tr>
<td>Brogan et al (2016)4</td>
<td>48</td>
<td>24</td>
<td>49.2 to 16.5</td>
<td>42.6 to 9.2</td>
<td>49.2 to 24.3</td>
</tr>
<tr>
<td>Brogan et al (2014)5</td>
<td>45</td>
<td>6</td>
<td>50.8 to 17.4</td>
<td>43.2 to 9.8</td>
<td>47.6 to 13.1</td>
</tr>
</tbody>
</table>

Table 5. MOXFQ Results From Other Studies Reporting Third-Generation Minimally Invasive Hallux Valgus Surgery.

Abbreviation: MOXFQ, Manchester-Oxford Foot Questionnaire.
commonly reported in other studies of third-generation MIS HV surgery. Tay et al\textsuperscript{50} and Castellini et al\textsuperscript{7} demonstrated improvement in the tibial sesamoid position following MICA and percutaneous double osteotomy respectively. We believe that the nature of a transverse osteotomy (ie, META) facilitates correction of the pronation HV deformity and thus
correction of the sesamoid position and round sign, although readers should be aware of the limitations of assessment of these parameters on radiographs alone (pseudo-sesamoid-subluxation). Future studies should incorporate weight-bearing CT scans to help accurately and precisely assess pre- and postoperative rotation correction following MIS HV surgery.

**Strengths**

The major strength of this series of consecutive cases was use of a wide range of validated pre- and postoperative clinical and radiographic outcome measures with no loss to follow-up. The series included all of the surgeons’ initial cases and so is indicative of challenges faced during the learning curve of the procedure. The series was powered for the primary outcome measure with a minimum-12 month follow-up. Detailed pre- and postoperative clinical and radiologic data were collected with no loss to follow-up. There was no exclusion based on radiographic deformity or additional lesser toe procedures reflective of clinical practice, suggesting these results are generalizable to a wider patient population.

**Limitations**

We acknowledge there were a number of limitations of this study. There was no comparison group, so we were unable to draw conclusions regarding the superiority of one procedure over another. This series was from a single surgeon who was fellowship trained by a design surgeon. Although formal training may become the norm in the future, this is not currently the case; therefore, the wide range of deformities treated in this series may not be expected during the learning curve of an independent surgeon learning this technique from training courses. Postoperative radiographs were not formally calibrated for length measurement; therefore, the shortening results presented here relied on an assumption of 120% magnification. The series was limited by the short follow-up period. Further long-term studies of both learning curve series and established series are needed to determine late complications and recurrence of this technique.

**Conclusion**

In this small cohort of patients from a single surgeon, the fourth-generation MIS technique is a safe and effective approach to hallux valgus deformity correction with significant improvement in clinical and radiographic outcomes across a wide range of deformities.

**Declaration of Conflicting Interests**

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Peter Lam, MBBS, FRACS, reports personal fees from Novastep, outside the submitted work. ICMJE forms for all authors are available online.

**Funding**

The author(s) received no financial support for the research, authorship, and/or publication of this article.

**ORCID iDs**

Thomas L. Lewis, MBChB, BSc, MRCS, MFSTEd, [https://orcid.org/0000-0002-4167-7427](https://orcid.org/0000-0002-4167-7427)

Benjamin Lau, BSc, MRCS, [https://orcid.org/0000-0002-7125-3983](https://orcid.org/0000-0002-7125-3983)

Peter Lam MBBS, FRACS, [https://orcid.org/0000-0001-7934-6546](https://orcid.org/0000-0001-7934-6546)

Rebbie Ray, MBChB, ChM(T&O), FRCSed(Tr & Orth), FEBOT, [https://orcid.org/0000-0002-7411-9720](https://orcid.org/0000-0002-7411-9720)

**References**


