**ORIGINAL ARTICLE**

# Clinical and radiological outcome of surgical hallux valgus correction: open versus minimally invasive

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## Abstract

**Introduction** Hallux valgus (HV) is the most common forefoot deformity. Surgical correction of HV aims to reduce pain, preserve joints, and re-establish foot function while restoring the hallux valgus angle (HVA) and intermetatarsal angle (IMA). Many surgical procedures have been proposed, including open and minimally invasive (MI) techniques. This study aimed to compare the midterm outcomes of open vs. MI procedures and their impact on the duration of surgery, hospital stay, HVA, and IMA post-operatively.

**Materials and methods** One hundred and twenty HV patients operated by open or MI surgery between October 2019 and October 2022 were included. One hundred three patients met the inclusion criteria and consented to the study. Patients were prospectively surveyed for foot functionality, post-operative pain, and complications using the AOFAS score. Radiographic measurements of HV angles, length of hospital stay, and surgery duration were analysed.

**Results** MI surgery patients had significantly better AOFAS scores ($p < 0.001$) 12 months post-operatively compared to open surgery. Complication rates were lower in the MI group (3.8% vs. 33.3%, $p < 0.001$). MI surgery patients also had shorter hospital stays ($0.9 \pm 0.3$ days vs. $2.0 \pm 0.0$ days) and surgery duration ($19.7 \pm 2.3$ min vs. $80.7 \pm 6.8$ min). MI surgery was more effective in correcting the IMA but equally effective as open surgery for HVA correction.

**Conclusion** MI surgery resulted in better patient satisfaction, fewer complications, and more precise correction of IMA values. Moreover, the duration of surgery and hospital stay were significantly lower in patients undergoing MI surgery. Further research is needed to validate these findings in controlled, prospective randomised trials.

**Keywords** Hallux valgus · Minimally invasive · Outcome · Intermetatarsal angle · Pain · Complication

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## Introduction

Hallux valgus (HV), commonly known as a bunion, has a global prevalence of 19–35% and primarily affects women aged 50–70 [1–4]. It is characterised by the progressive abduction and pronation of the first phalanx and the adduction, pronation, and elevation of the first metatarsal (MT). HV can cause significant metatarsalgia [5, 6].

Diagnoses are primarily clinical, supported by radiographic measurements of the hallux valgus angle (HVA) and the intermetatarsal angle (IMA), which allow classification of the deformity severity.

Many surgical and nonsurgical treatments for HV have been proposed, but outcomes vary regarding foot function, pain, and complication rates [7–11].

This study aims to compare the midterm outcomes of open surgical techniques (e.g. Chevron-Austin, Lapidus,

and Scarf osteotomies) versus a third-generation minimally invasive proximal osteotomy with bicortical screw fixation.

## Materials and methods

### Study design

The present study is a retrospective, single-centre, descriptive observational study with prospectively collected post-operative patient data. It compares the effectiveness and safety of minimally invasive and open surgical procedures for HV correction. One hundred and twenty patients treated between October 2019 and October 2022 met the eligibility criteria, of which 103 (i.e. 14.2% drop-out rate) completed the follow-up examination. This trial was not randomised; treatment decisions were based on surgeon expertise, patient preference, and specific clinical indications. Once HV deformity was diagnosed and surgery was indicated, a decision on MI or open surgery was made based on the preferred method by the patients.

### Inclusion and exclusion criteria

Inclusion criteria

- Clinical diagnosis of HV surgical indication
- Age > 18 years
- Consent to participate

    Exclusion Criteria

- Severe deformities requiring more extensive surgical procedures (i.e. claw toe, hammer tow)

- Presence of polyneuropathy or other medical conditions affecting surgical outcomes
- Pregnancy or lactation
- Allergies to materials and medications used intraoperatively and post-operatively

Foot functionality was assessed using the standardised AOFAS score before and after the surgery. A total of 51 patients underwent the open surgical procedure, while 52 patients received the minimally invasive treatment (see also the study flow chart in Fig. 1).

Before commencing data collection, the study was submitted to and approved by the relevant ethics committee (Reference Number: Eth—22/2022). Care was taken to ensure that data collection and processing complied with data protection regulations.

### Surgical procedures

MI and open procedures followed standard protocols with general anaesthesia or nerve blocks and prophylactic antibiotics. The patient was positioned on the operating table in a supine position; subsequently, the foot region was prepped and draped in the usual sterile fashion.

In open surgery, an incision was made along the lateral side of the first metatarsal–phalangeal joint (MTPJ). The underlying soft tissues were carefully prepared, and the abductor hallucis muscle was gently retracted. The first step was the arthrotomy with proximal exostosis osteotomy of the first metatarsal bone (MTP-I). Depending on the method chosen, an osteotomy of the first metatarsal bone (MTP-I) was performed (Austin operation). The osteotomy was aligned to correct the IMA. The osteotomy was then stabilised using a sturdy plate and screws, ensuring correct
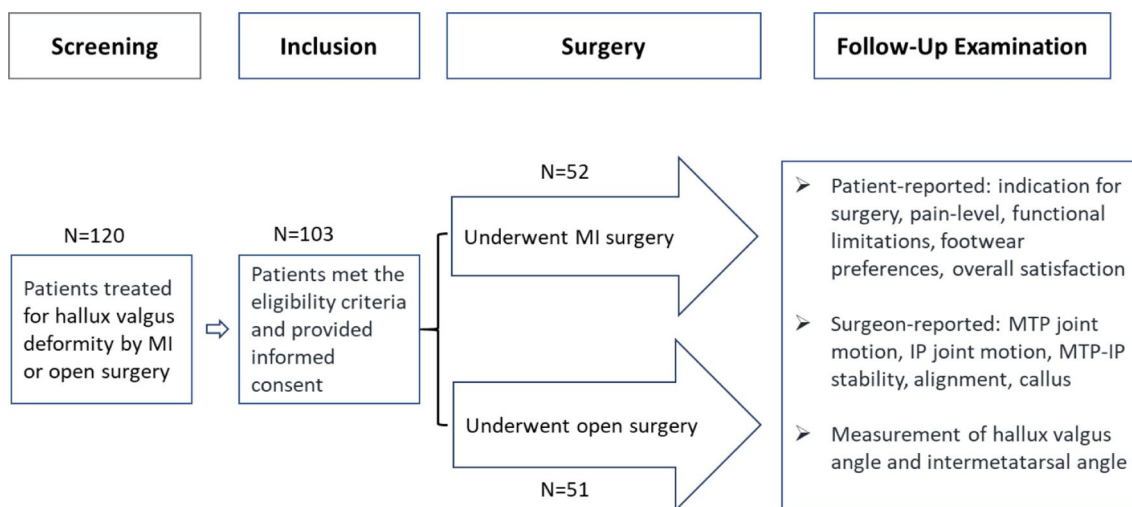


**Fig. 1** Study flow chart

bone positioning. Finally, the soft tissues were meticulously closed, and a sterile dressing was applied to protect the wound.

MI surgery involved a small incision, a three-dimensional wedge osteotomy using Shannon bur, and stabilisation with a magnesium or titanium screw (Fig. 2). Pre- and post-operative X-rays are depicted in Fig. 3. Lateral release was performed using beaver knife. A single senior surgeon performed all procedures to ensure consistency (Fig. 2). Subsequently, the wound was closed.

## Statistical analysis

Primary outcomes (AOFAS score changes) were analysed using t tests for independent samples, while secondary outcomes (IMA and HVA changes) were analysed



**Fig. 2** A: Post-operative clinical image, **A** and X-ray, **B** after minimally invasive proximal osteotomy and screw fixation



**Fig. 3** Example of pre- and post-operative X-rays following MI surgery

exploratorily. The primary outcome was analysed using a t test for independent samples at a significance level of 0.05. Cohen's d is calculated to interpret the strength of the effect [12]. The following reference values help classify the effect size: $d > 0.2$ = small effect, $d > 0.5$ = moderate effect, and $d > 0.8$ = strong effect.

Baseline demographics and comorbidities were compared using t tests, Pearson's Chi-square, and Fisher's exact tests. The statistical analysis was performed using SPSS version 28 (IBM, Armonk, NY, USA).

## Results

### Baseline characteristics

Patients in the MI group were significantly older ($p = 0.0024$) than those in the open surgery group. Both groups had similar distributions of gender and obesity (according to the WHO definition, the threshold for obesity is defined here as a body mass index of $>= 30$). Still, the MI group had more pre-existing conditions (Table 1).

Diabetes mellitus type II, arterial hypertension, coronary heart disease, and rheumatism were more prevalent in patients in the MI group, with no significant difference between both groups. Pain was the main reason for surgery in both groups, frequently combined with

mobility limitations. The average time between surgery and follow-up was 382 ($\pm 222$ SD) days. The follow-up time differed only slightly between both groups (open surgery group: $365 \pm 154$ vs. MI group: $399 \pm 271$; $p = 0.44$).

### Primary outcome

MI surgery patients showed significantly more significant improvements in AOFAS scores compared to the open surgery group (t test: $t = 12.454$, df = 101, $p < 0.001$). The mean difference in change from baseline scores was 33.624 (95% confidence interval: 28.268–38.980), with a mean difference in the MI group of 60.2 ($\pm 12.1$ SD) compared to a mean difference in the open surgery group of 26.5 ($\pm 15.1$ SD), which corresponds to a large effect (Cohen's $d = 2.453$, 95% CI: 1.941–2.964). The baseline FFI scores were lower in the MI group, but post-operative scores were significantly higher. To ensure that differing baseline scores do not confound the analysis of AOFAS change from baseline scores, post-operative values were also compared using an independent samples t test, yielding significant results ($p < 0.001$). The average post-operative AOFAS scores were significantly higher in patients after MI surgery (MI: $94.5 \pm 6.9$ SD vs. open: $75.9 \pm 13.4$ SD, see Table 2 and Fig. 4).

**Table 1** Patients' baseline characteristics

| Variable | MI surgery (N=52) | Open surgery (N=51) | p value MI versus open | Total (N=103) |
|---|---|---|---|---|
| Age, Average ± SD [Range] | 62.0 ± 13.3 [24–80] | 53.9 ± 12.9 [22–77] | 0.024* | 58.0 ± 13.6 [22–80] |
| Gender, n (%) | | | 1.000 | |
| Female | 48 (92.3) | 47 (92.2) | | 95 (92.2) |
| Male | 4 (7.7) | 4 (7.8) | | 8 (7.8) |
| Obese, n (%) | 4 (7.7) | 6 (11.8) | 0.526 | 10 (9.7) |
| Deformities | | | 0.002* | |
| Splayfoot, Pes plano valgus | 44 (84.6) | 46 (90.2) | | 90 (87.4) |
| Splayfoot, Pes plano valgus, Small toe deformities | 7 (13.5) | 0 (0.0) | | 7 (6.8) |
| Splayfoot | 1 (1.9) | 5 (9.8) | | 6 (5.8) |
| Pre-existing conditions#, n (%) | 34 (65.4) | 23 (45.1) | 0.038* | 57 (55.3) |
| Reason for surgery | | | 0.012* | |
| Pain, Mobility limitations | 21 (40.4) | 24 (47.1) | | 45 (43.7) |
| Pain | 20 (38.5) | 18 (35.3) | | 38 (36.9) |
| Mobility limitations | 1 (1.9) | 5 (9.8) | | 6 (5.8) |
| Pain, Cosmetics | 4 (7.7) | 2 (3.9) | | 6 (5.8) |
| Pain, Cosmetics, Mobility Limitations | 4 (7.7) | 2 (3.9) | | 6 (5.8) |
| Cosmetics, Mobility limitations | 2 (3.8) | 0 (0.0) | | 2 (1.9) |

*MI* minimally invasive, *SD* standard deviation, *N* number of patients, % proportion of patients. *$p < 0.05$, #considered were diabetes mellitus type II, arterial hypertension, coronary heart disease, rheumatism

**Table 2** AOFAS scores—MI group versus open surgery group

| Variable | MI surgery (N=52) | | | Open surgery (N=51) | | | p value |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Range | Mean | SD | Range | MI versus open |
| AOFAS score baseline | 34.3 | 11.3 | 19–70 | 49.4 | 12.1 | 22–72 | < 0.0001 |
| AOFAS score post-operative | 94.5 | 6.9 | 75–100 | 75.9 | 13.4 | 32–97 | < 0.0001 |
| AOFAS score change from baseline | 60.2 | 12.0 | 30–81 | 26.5 | 15.0 | 3–66 | < 0.0001 |

*MI* minimally invasive, *SD* standard deviation, *N* number of patients

**Fig. 4** AOFAS scores—MI group versus open surgery group
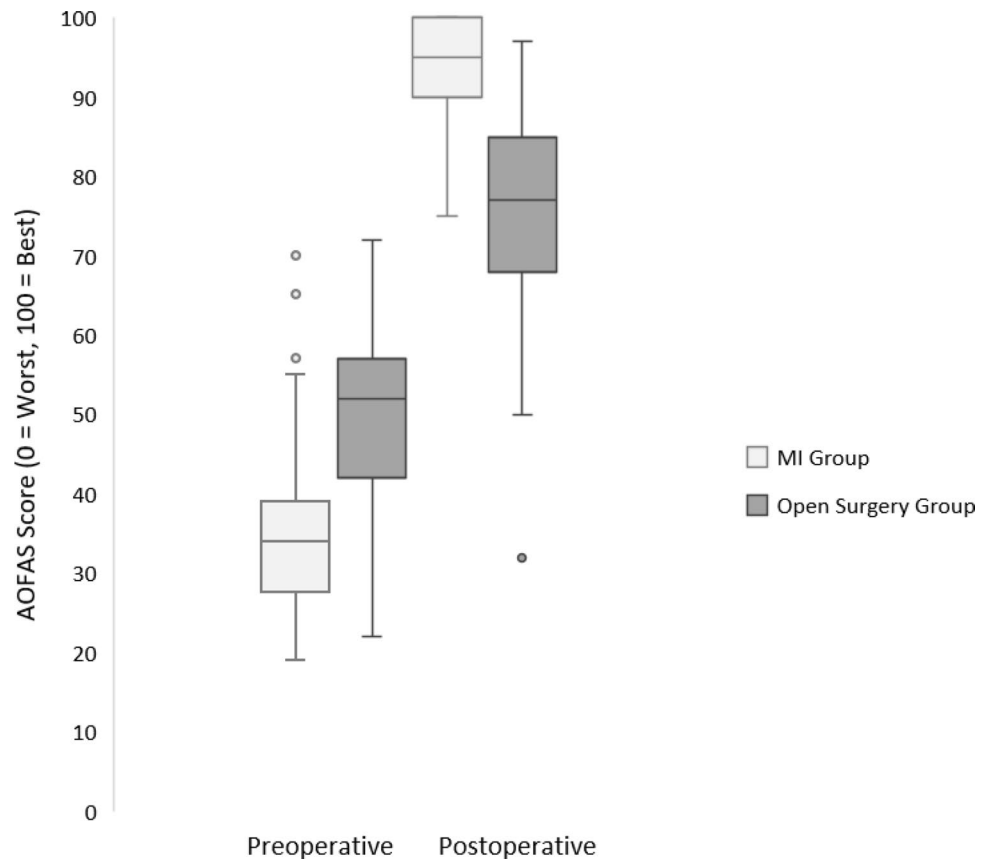


## Subgroup analysis by IM angle deformity

In the open surgery group, 31 (60.8%) patients had an initial IM angle deformity of less than 20 degrees and 20 (39.2%) patients had an initial IM angle deformity of greater than 20 degrees. There were 9 (17.6%) patients with an initial IM angle of < 20 degrees versus 42 (82.4%) patients with an initial IM angle of > = 20 degrees in the MI group.

In the group of patients with an initial IM angle of < 20 degrees, the mean difference in change from baseline scores was 33.638 (95% confidence interval: 29.027–38.249), with a mean difference in the MI group of 56.4 ($\pm$ 10.8 SD) compared to a mean difference in the open surgery group of 22.8 ($\pm$ 12.7 SD), which corresponds to a large effect (Cohen's d = 2.852, 95% CI: 2.304–3.401). In the group of patients

with more severe IM angle deformity, the mean difference in change from baseline scores was 28.630 (95% confidence interval: 23.174–34.087), with a mean difference in the MI group of 60.9 ($\pm$ 12.1 SD) compared to a mean difference in the open surgery group of 32.3 ($\pm$ 16.4 SD), which corresponds to a large effect (Cohen's d = 1.993, 95% CI: 1.533–2.452)).

## Secondary outcomes

Post-operative IMA was significantly lower in the MI group ($3.1 \pm 0.9°$ vs. $8.8 \pm 2.2°$, $p < 0.001$), while HVA correction was similar between groups (Fig. 5). As for post-operative HVA, it averaged 2.1 degrees ($\pm$ 0.8 SD) for minimally invasive surgery and 2.8 degrees ($\pm$ 0.9

**Fig. 5** HV angle and IM angle—MI group versus open surgery group
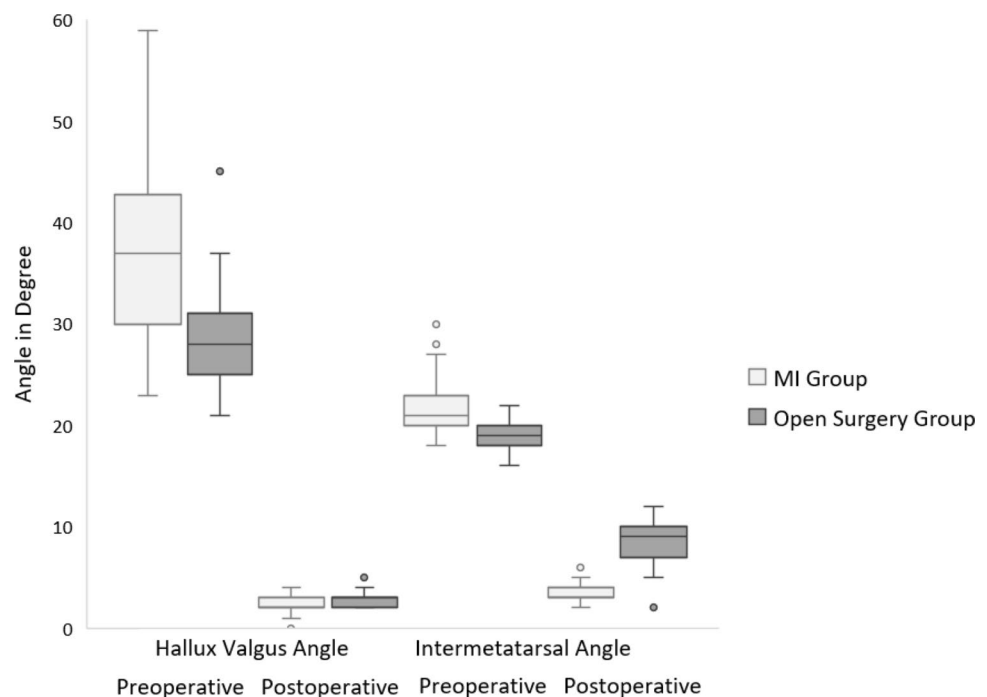


SD) for open surgery. The difference between the two procedures was not statistically significant ($p = 0.120$). Preoperatively, IMA averaged 22.0 degrees ($\pm 2.9$ SD) for MI surgery and 19.1 degrees ($\pm 1.4$ SD) for open surgery, and HVA averaged 37.5 degrees ($\pm 8.9$ SD) for MI surgery and 28.2 degrees ($\pm 4.3$ SD) for open surgery. Thus, both preoperative angles were slightly larger on average in the MI group than in the open surgery group. Accordingly, the reductions in both angles between preoperative and post-operative values were significantly greater for MI surgery patients ($p < 0.001$ for both IMA and HVA). The complication rate was significantly lower in the MI group (3.8% vs. 33.3%, $p < 0.001$). Surgery duration and hospital stay were also shorter in the MI group.

While only two patients (3.8%) reported one or more complications in the MI group, 17 patients (33.3%) suffered from one or more complications in the open surgery group, resulting in a significantly lower complication rate in the MI group ($p < 0.001$).

Only two cases of persistent swelling were documented after MI surgery. Following open surgery, persistent swelling was noted in nine patients (17.7%), five (9.8%) patients complained of continuous pain, and four (7.8%) had wound-healing complications. Pseudarthrosis, infection, material breakage, and the need for revision surgery occurred in a maximum of two cases.

## Pain, functionality, satisfaction, length of hospital stay, and surgery duration

Preoperative pain levels were similar between both groups (MI: 3.2, open: 2.9). Post-operatively, pain levels reduced significantly (MI: 1.2, open: 1.9). Functionality scores showed no significant preoperative differences (MI: 2.7, open: 2.6) but improved post-operatively (MI: 1.2, open: 1.8).

Patient satisfaction was higher in the MI group (MI: 1.7, open: 2.3). Surgeries were shorter for the MI group ($19.7 \pm 2.3$ min vs. $80.7 \pm 6.8$ min), and hospital stays were shorter (MI: $0.9 \pm 0.3$ days vs. open: $2.0 \pm 0.0$ days).

## Discussion

Minimally invasive (MI) techniques for HV correction have gained popularity due to advantages like limited tissue dissection, smaller wounds, reduced operation time, and lower costs [13]. Despite over 150 surgical procedures described, high-evidence prospective studies are scarce, and the optimal treatment modality remains controversial [14–17].

This study used a third-generation MI technique involving proximal osteotomy with a stable bicortical fixation using a

titanium screw, as described by Brogan et al. [5]. Previous techniques, like the Reverdin-Isham osteotomy without fixation, had high complication rates leading to abandonment in favour of more stable screw fixations [18–20]. Therefore, the authors recommend stable bicortical screw fixation instead of K-Wire fixation.

This study evaluated patient outcomes after MI or open HV correction without accompanying deformities, including pain, functionality, and patient satisfaction.

MI surgery showed better overall clinical outcomes, with significantly higher post-operative AOFAS scores (MI: $94.5 \pm 6.9$ vs. open: $75.9 \pm 13.4$). This improvement comprised all individual AOFAS items: pain, functionality, and patient satisfaction. Even if there were significant differences between the two groups in preoperative parameters that may influence patient outcomes, biased results are very unlikely. Despite more severe preoperative conditions in the MI group, both the post-operative and the change from baseline AOFAS scores were clearly superior to the values in the open group.

Our results align with a meta-analysis by Ji et al., which found higher AOFAS scores and less post-operative pain for MI procedures. The authors conclude that MI procedures were more effective in the treatment of HV and achieved better radiological and clinical outcomes [15]. Lu et al. had similar findings, though without significant AOFAS improvements [16, 21].

Conversely, Kaufmann et al. reported no significant differences between MI and open chevron osteotomy regarding pain, AOFAS scores, radiographic outcomes, range of motion, or patient satisfaction [16]. Singh et al. concluded that while MI procedures provided satisfactory results for moderate HV cases, open surgery yielded better functional outcomes [22]. It is worth mentioning that the follow-up duration between these studies is extremely variable, ranging from 6 months to 8 years, and differing surgical techniques, which, in our view, limit the interpretation of meta-analyses in HV surgery [22–24]. Similarly, Alimy et al. [1] did not identify significant advantages of MI surgery over open procedures. However, they did observe a discrete benefit of MI surgery in terms of post-operative pain and cosmetic results [25].

Interestingly, our study showed a significantly lower complication rate for MI surgery (3.8% vs. 33.3%, $p < 0.001$). Complications in HV correction, such as under-correction, overcorrection, nonunion, malunion, avascular necrosis, infection, nerve injury, and patient dissatisfaction, occur in 10–55% of cases [26, 27]. The three-dimensional osteotomy technique used in MI surgery reduces recurrence and metatarsal misload [28, 29].

Concerning functionality, operation time, and hospital stay the present study was also in line with previous literature [22, 30, 31].

Another interesting finding of the current study is a significantly reduced operation time ($19.7 \pm 2.3$ min vs. $80.7 \pm 6.8$ min). Time-consuming tissue dissection can be omitted using MI techniques. Furthermore, hospital stay was significantly shorter ($0.9 \pm 0.3$ days vs. $2.0 \pm 0.0$ days) in the MI surgery group. Similar results have been reported in the literature and favour MI techniques over open surgery.

## Radiological outcome

Radiologically, MI surgery was more effective in restoring IMA, with no significant difference in HVA correction between groups. No cases of nonunion, osteonecrosis, or early recurrence were observed. Kaufmann et al. found similar IMA and HVA reductions in both groups, while Vieira Cardoso et al. reported better IMA reduction with open surgery. This discrepancy could be due to the learning curve associated with MI techniques [16, 20]. Unlike Chan et al., we did not observe a discrepancy between clinical outcomes and angle measurements. However, clinical and radiological outcomes are generally known not to have a linear correlation [32, 33].

While the operative technique in the mentioned study from Kadakia et al. involved a fixation with K-wires, a more stable fixation can be achieved using a titanium screw. It should also be noted that the authors recommend a bicortical screw fixation.

## Limitations

The current study is limited by the inherited deficiencies of a prospective study and a short follow-up time. In addition, we acknowledged that surgery was performed at one single centre and carried out by a single senior surgeon specialising in foot and ankle surgery. To confirm the encouraging results of the current study, large-scale randomised controlled trials with sufficient follow-up are needed.

## Conclusion

This study compared open and MI HV correction procedures, finding that MI surgery resulted in better pain reduction, functionality, patient satisfaction, lower complication rates, greater IMA correction, reduced operation times, and shorter hospital stays. Further randomised controlled trials are necessary for broader adoption and verification of these results.

## Declarations

**Conflict of interest** All authors have no conflict of interest.

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