



Radiographic and clinical outcomes of minimally invasive surgery versus open osteotomies for the correction of hallux valgus

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Abstract

Purpose Hallux valgus is a common disease which causes pain and dysfunction of the foot. Although numerous methods of procedures have been introduced, a single procedure cannot correct all deformities of hallux valgus. The study aims to evaluate the radiographic and clinical effectiveness of a new minimally invasive surgery (MIS) versus open Chevron-Akin procedures.

Methods This was a retrospective comparative study. Data were collected from May 2018 to January 2020. A total of 27 patients (31 feet) undergoing MIS for hallux valgus were included in this study. The average age of patients underwent MIS was 59.9 years. The mean follow-up was 25.1 months. Open osteotomies were performed in 30 patients (31 feet) during the same period. The mean age of these patients at the time of surgery was 59.1 years. The mean follow-up was 26.1 months. Pre-operative and post-operative radiographic outcome measures included HVA, IMA, DMAA, the Sgarlato's angle and the length of the first metatarsal, and distance between the dorsal cortex of first and second metatarsal necks. The AOFAS and VAS were used to assess foot function.

Results The preoperative HVA in MIS group and open group were 34.8° and 33.1° respectively. The post-operative HVA were 20.4° and 13.7°. The pre-operative IMA in MIS group and open group were 13.0° and 12.1°. The post-operative IMA were 11.4° and 5.5° respectively. The pre-operative DMAA were 14.8° and 15.1° respectively. The post-operative DMAA were 6.3° and 8.7°. The AOFAS increased from 44.0 to 90.2 in MIS group and from 47.6 to 89.5 in open group. The VAS decreased from 7.3 to 1.3 in MIS group and from 7.1 to 1.2 in open group.

Conclusion Although open osteotomies were superior than MIS in HVA and IMA, MIS showed advantages in correcting DMAA. MIS provided equivalent functional outcomes compared to open surgery.

Keywords Hallux valgus · Osteotomy · Minimally invasive surgery

Introduction

Hallux valgus is a common forefoot deformity commonly referred to as a bunion deformity affecting more than 23% of adults [1, 2]. Hallux valgus is characterized by progressive adduction and elevation of the first metatarsal and abduction and pronation of the proximal phalanx of the hallux [3]. Various methods have been introduced to treat hallux valgus deformity. Minimally invasive surgery (MIS) is drawing more and more attention and it has achieved high levels of patient

satisfaction and successful deformity correction recently in patients with mild to severe hallux deformities [4–7]. Numerous studies including clinical and cadaveric studies of MIS demonstrated radiographic correction, pain, and function improvement when compared with open osteotomies [8–14]. Open Chevron is widely accepted as a mature technique. However, scarring and reduced range of motion may occur as a consequence of open approach [15]. MIS has the advantages of less operative trauma and preservation of the blood supply, while it has the potential risk of shortening of the first ray and recurrence [16]. Usually, the hallux valgus MIS was divided into three generations [17]. The first generation included mainly the Reverdin-Isham procedure, with 5 to 73% complication rates [6]. The second generation was first described by Bösch and characterized by a distal transverse osteotomy stabilized with K-wires [18]. But the surgical site infection

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rate ranged from 0.8 to 8.8 because of the K-wires. The third generation consisted of minimally invasive Chevron and Akin osteotomies. The percutaneous Chevron osteotomy was fixed by two parallel screws. Lewis et al. studied 292 cases with a minimum follow-up of two years [19]. The overall complication rate was 21.3%. The all-cause screw-removal rate was 6.3%. Given the high complication rate, we wanted to perform a new and simple MIS.

We performed a percutaneous oblique distal metatarsal osteotomy to correct the hallux valgus. This current study compared open surgeries to the results of using MIS. The open osteotomies employed Chevron osteotomy with Akin osteotomy. We hypothesized that the two techniques would show significant differences with regard to radiographic and clinical outcomes.

Methods

This was a retrospective comparative study carried from May 2018 to January 2020. Data were collected consecutively. Approval for this study was obtained from our hospital's institutional review board.

Patients older than 18 years old with hallux valgus were considered for participation. The exclusion criteria were (1) previous first metatarsal osteotomy or other surgery, (2) osteoarthritis of the first metatarsophalangeal joint, and (3) soft tissue infection near the incision site.

Outcome measures

Standard weight-bearing dorsoplantar and lateral radiographs of feet were taken pre-operatively and post-operatively. Hallux valgus angle (HVA), intermetatarsal angle (IMA), distal metatarsal articular angle (DMAA), length of the first metatarsal, the modified Sgarlato's angle, and vertical difference in millimeters between the dorsal cortex of the first and second metatarsal necks were measured [1, 20]. The HVA was defined as the angle between the central longitudinal axis of the first metatarsus and proximal phalanx. The IMA was defined as the angle between the central longitudinal axis of the first and second metatarsals. The DMAA refers to the angle formed between the articular surface of the head and a line perpendicular to the shaft of the first metatarsal. The Sgarlato's angle was subtended by a line drawn along the longitudinal axis of the second metatarsal and a line drawn perpendicular to the axis of the lesser tarsus. The axis of the lesser tarsus was drawn by intersecting the midpoint of the line from the lateral-most aspect of the calcaneocuboid joint to the lateral-most aspect of the fifth metatarsocuboid joint and the midpoint of a line from the most medial aspect of the talonavicular joint to the most medial aspect of the first tarsometatarsal (TMT) joint.

This angle represented the metatarsus adductus. The length of the first metatarsus was measured along the axis of the first metatarsus in the lateral weight-bearing X-ray of foot from the most distal aspect to the most proximal aspect. The vertical difference in millimeters between the dorsal cortex of the first and second metatarsal necks (1,2 gap) represented the elevation of the first metatarsal. We used the American Orthopaedic Foot & Ankle Society Score Hallux Metatarsophalangeal-Interphalangeal Scale (AOFAS) and Visual Analogue scale (VAS) to determine the functional outcome of patients before the surgery and at the final follow-up [21].

Radiographs were obtained 6 weeks, 3 months, and 1 year after the index procedure. Also, patients were required to take a weight-bearing X-ray of foot at the final follow-up Figs. 1 and 2.

Operative technique

For patients undergoing MIS, they were positioned supine on the operating table under general anaesthesia. The adductor hallucis was released if there existed tension when great toe returned to normal position passively. This procedure was performed through a small incision between the heads of the first and second metatarsal. A 3-mm incision was made at the dorsal medial aspect of the head of the first metatarsal to avoid the extensor digitorum longus tendon. Then a 2-mm burr was used to resect the prominent bone ridges of the first metatarsal through this incision, an oblique subcapital osteotomy from the dorsal side of head of first metatarsal to the plantar side. The remaining bone meal was rinsed out with ice sterile saline to cool the osteotomy to avoid burn of bone in case of bone nonunion. The distal part of metatarsal could be shifted or rotated laterally as necessary. We usually corrected the DMAA and shifted the



Fig. 1 The vertical difference in millimeters between the dorsal cortex of the first and second metatarsal necks



Fig. 2 Radiologic measures assessing degree of hallux valgus. **A** (1) HVA: the angle between long axis of the first metatarsal and the proximal phalanx. (2) IMA: the angle between the central longitudinal axis of the first and second metatarsal. **B** DMAA: the angle between the articular surface of the head and a line perpendicular to the shaft of the first metatarsal. **C** The modified Sgarlato's angle: the angle subtended by a line drawn along the longitudinal axis of the second metatarsal

distal metatarsal to the lateral side simultaneously. One or two guide pins were placed from proximal to distal to fix the osteotomy. Intra-operative fluoroscopy was used to assess the adequacy of the correction of deformity and position of the guide pins. Then one to two 2.5-mm-diameter cannulated screws (Wright, TN, USA) were placed through guide pins. For patients with hallux valgus interphalangeus, percutaneous Akin osteotomy was indicated. A small incision (3 mm) was made at the medial side approximately 2 cm distal to the metatarsophalangeal joint. A percutaneous Weil osteotomy was performed without fixation, if the patient had metastatic metatarsalgia Fig. 3.

For patients undergoing open osteotomy, the adductor hallucis was released as stated above. Then a medial longitudinal incision was performed at the first metatarsophalangeal joint. The capsule of the first metatarsophalangeal joint was stripped like V shape. The osteophyte at the medial side of head of metatarsal was cut. We performed a Chevron osteotomy on the head of the first metatarsal. The distal part was moved laterally. Two crossed cannulated screws (3.2 mm, Wright, USA) were used to fix the osteotomy. The incision was prolonged to the proximal phalanx. An akin osteotomy was performed at the proximal phalanx and it was fixed by one straddle nail (Wright, USA). The Weil osteotomy was performed using the breaking screws (Wright, USA). The intra-operative C-arm was used to make sure that deformity got adequately correctly.

atarsal and a line drawn perpendicular to the axis of the lesser tarsus. The axis of the lesser tarsus was drawn by intersecting the midpoint of the line from the lateral-most aspect of the calcaneocuboid joint to the lateral-most aspect of the fifth metatarsocuboid joint and the midpoint of a line from the most medial aspect of the talonavicular joint to the most medial aspect of the first tarsometatarsal joint

Post-operative management

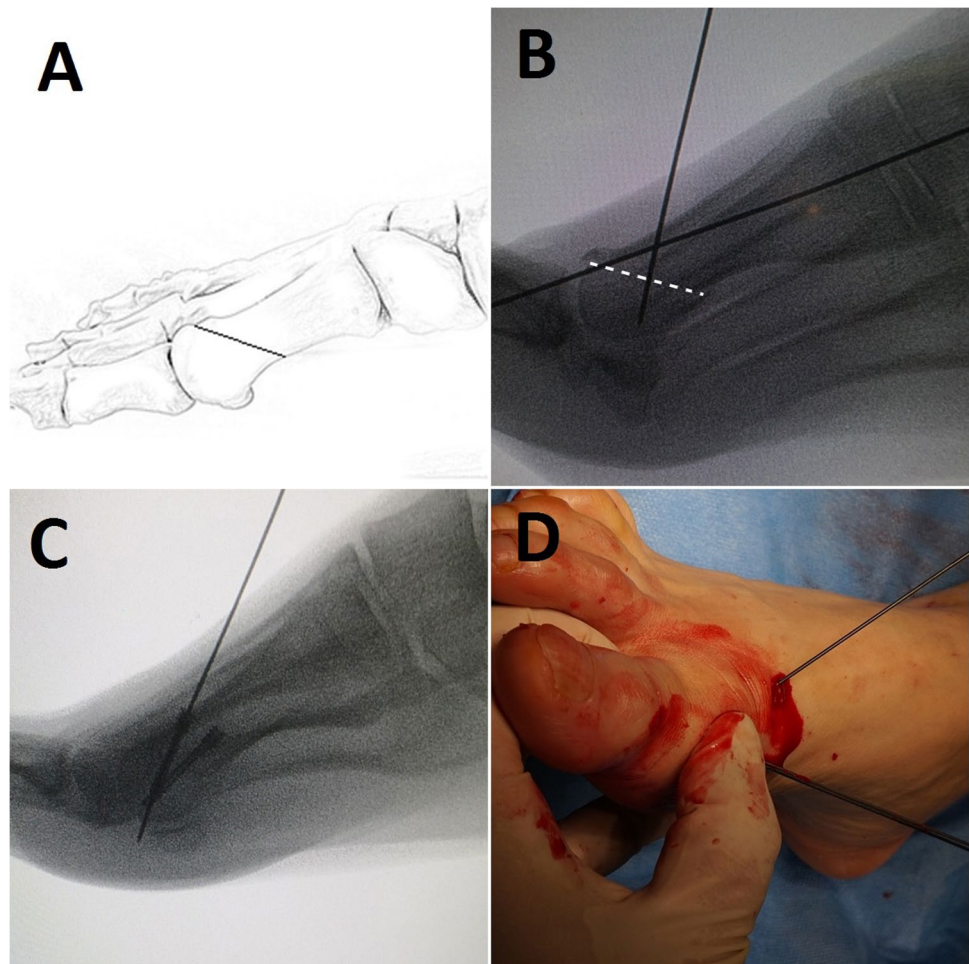
Patients undergoing MIS were instructed to wear rigid-sole flat shoes one day after surgery. Patients undergoing open surgery were instructed to wear shoes that could decrease weight-bearing onto the forefoot at the same time. Dearden et al. reported that both rigid-sole flat shoe and reverse camber shoe had comparable post-operative outcomes of pain relief and enabled patients to mobilize [22].

A proper bandage was applied after operation to hold the union in the neutral position avoiding overcorrection. Passive motion of the first metatarsophalangeal joint was allowed two weeks post-operatively. Full weight-bearing walk was allowed six weeks after surgery.

Statistical analysis

Descriptive statistics were used to report patient demographic data. All analyses were performed with SAS software version 8.1 (SAS Institute Inc., Cary, NC). The results were presented as the mean and standard deviation. The student *t* test was used to compare the difference between the MIS group and the open group in radiographic measurements and functional scores. P values below 0.05 were considered significant.

Fig. 3 Minimally invasive surgery. **A** Draft of the osteotomy line. **B** Intra-operative fluoroscopy of the osteotomy. **C** The osteotomy was fixed by two screws. **D** The intra-operative photo of surgery



Results

Twenty-seven female patients (31 feet, 14 right and 17 left) underwent MIS for hallux valgus were included in this study. One patient underwent a simultaneous flatfoot surgery. Four patients (5 feet) did not undergo percutaneous Weil osteotomy. In the open group, 22 patients (23 feet) underwent Weil osteotomy. One patient underwent a second MTP joint replacement because of the severe osteoarthritis of 2nd MTP joint. The average age of patients underwent MIS was 59.9 years (range, 29 to 86 years). The mean follow-up was 25.1 months (range, 19–39 months). Thirty patients (31 feet, 21 left and 10 right) underwent open osteotomies during the same time period were also collected. Among them, three were male. The mean age of these patients at the time of surgery was 59.1 years (range, 20–83 years). The mean follow-up was 26.1 months (range, 19–39 months).

The pre-operative HVA in the MIS group and the open group were 34.8° and 33.1° respectively ($p = 0.409$). The post-operative HVA were 20.4° and 13.7° ($p = 0.0009$). The pre-operative IMA in MIS group and open group were 13.0° and 12.1° ($p = 0.2504$). The post-operative

IMA were 11.4° and 5.5° respectively ($p < 0.0001$). The pre-operative DMAA were 14.8° and 15.1° respectively ($p = 0.8704$). The post-operative DMAA were 6.3° and 8.7° ($p = 0.0365$). The pre-operative Sgarlato's angles were 18.4° and 18.8° ($p = 0.777$), while the post-operative Sgarlato's angles were 16.8° and 16.5° ($p = 0.821$). The pre-operative lengths of first metatarsal were 59.1 mm and 60.2 mm respectively ($p = 0.3558$), while the post-operative lengths were 53.1 mm and 57.7 mm ($p = 0.0076$). The pre-operative vertical differences in millimeters between the dorsal cortex of the first and second metatarsal necks were 2.9 mm and 3.0 mm respectively ($p = 0.5295$). The post-operative differences were 3.0 mm and 3.4 mm ($p = 0.5922$). The AOFAS increased from 44.0 to 90.2 in MIS group and from 47.6 to 89.5 in open group. The VAS decreased from 7.3 to 1.3 in MIS group and from 7.1 to 1.2 in open group Fig. 4.

In the MIS group, none underwent revision operation. One patient removed internal fixation three months post-operatively and another one year post-operatively. Three patients had post-operative metatarsalgia. In the open group, three patients removed internal fixation one year postoperatively.

Fig. 4 A 60-year-old woman underwent MIS **A** before and **B** after surgery. **C** The osteotomy line

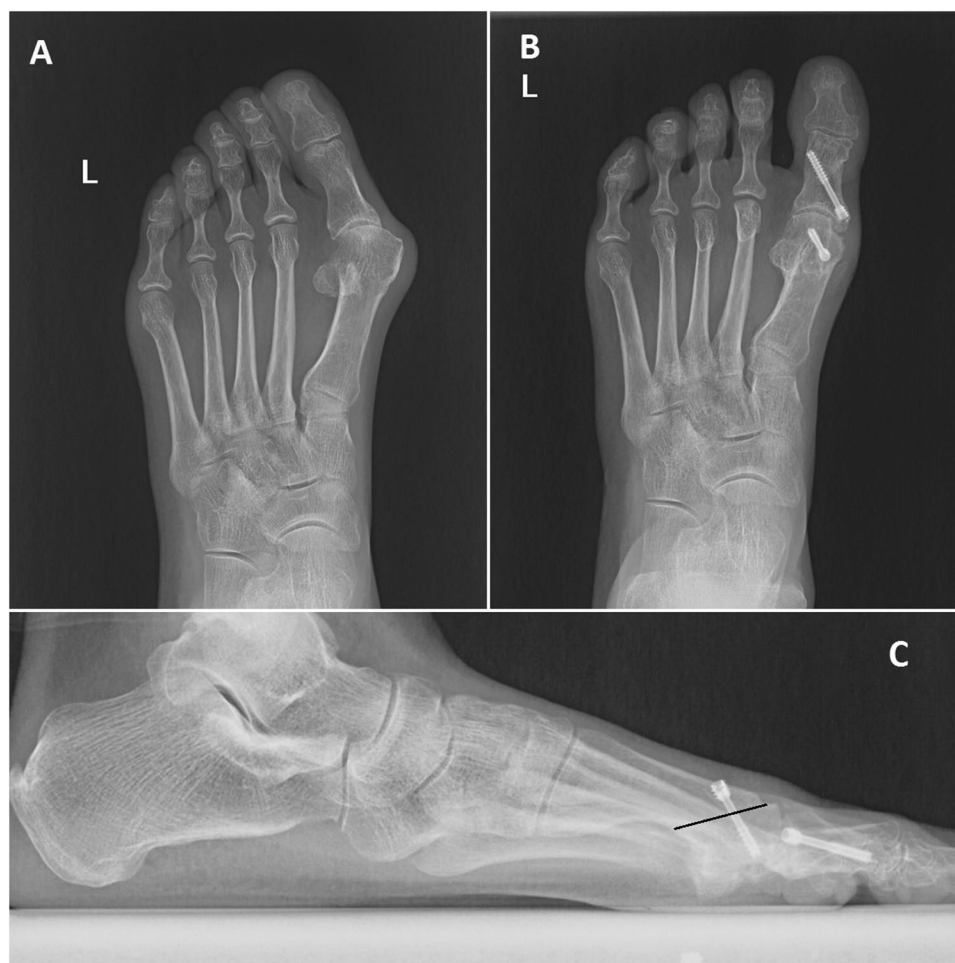


Table 1 Summarized demographic data

| Parameter | MIS | Open |
|--------------------------------------|------------|------------|
| Number of patients(feet), <i>n</i> | 27 (31) | 30 (31) |
| Male:female, <i>n</i> | 0:27 | 3:27 |
| Side (left:right) | 17:14 | 21:10 |
| Age at surgery | 59.9 | 59.1 |
| Mean follow-up, months | 25.1 | 26.1 |
| 2nd operation, <i>n</i> | 0 | 1 |
| Concomitant procedures, <i>n</i> (%) | | |
| Akin | 17 (54.8%) | 16 (51.6%) |
| 2nd or 3rd metatarsal osteotomy | 23 (74.2%) | 22 (71.0%) |
| Calcaneal osteotomy | 1 (3.2%) | 0 (0) |
| 2nd MTP replacement | 0 (0) | 1 (3.2%) |

One patient underwent revision surgery because of recurrence of deformity and pain. Two patients had hallux rigidus Tables 1 and 2, Figs. 5 and 6.

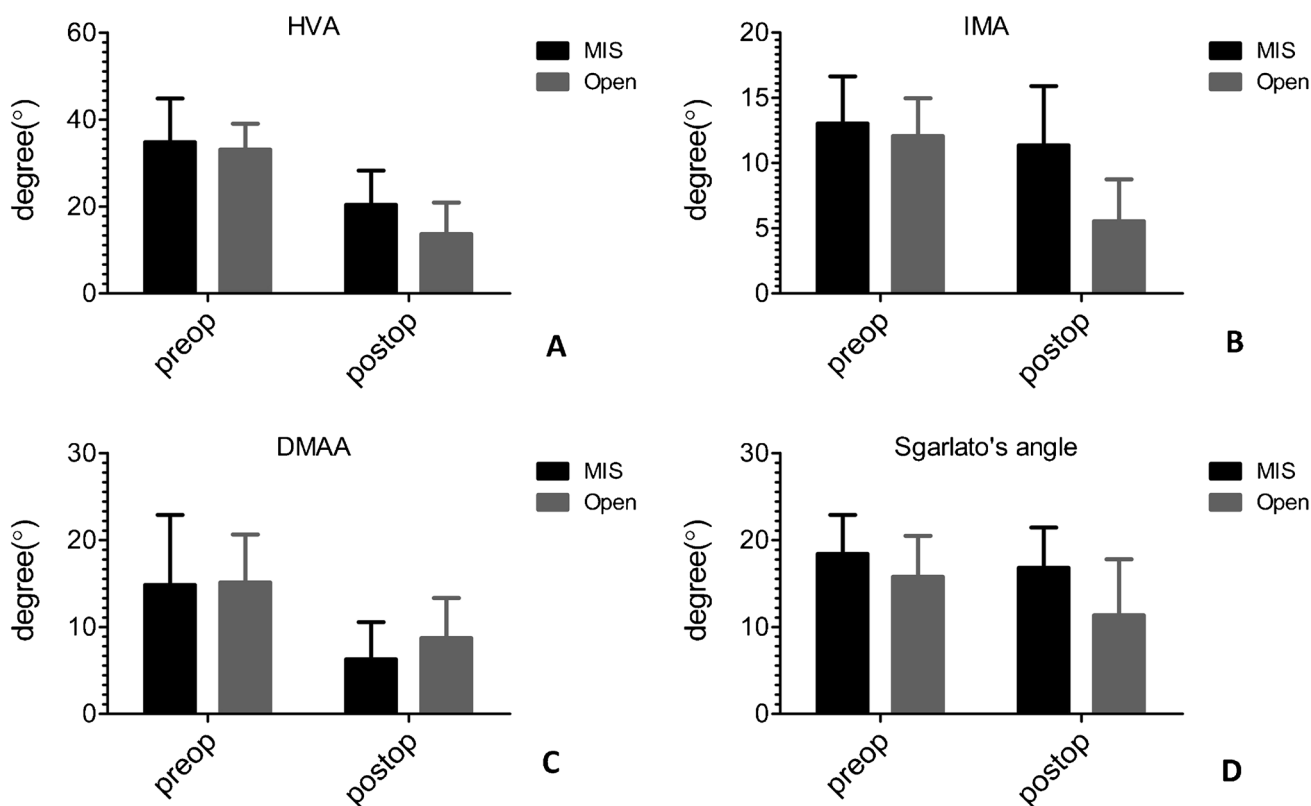
Discussion

Numerous studies have reported good outcomes of MIS distal metatarsal osteotomy, providing comparable good results in the correction of deformity and symptoms [6–9, 13, 14, 23, 24]. Different shapes of osteotomies have been adopted to perform the distal metatarsal osteotomy. In 2007, Kadakia et al. reported that nine in 13 patients had dorsal malunion in their study. However, in their study, the osteotomy was performed vertically and fixed by two Kirschner wires [25]. We performed a new percutaneous oblique distal metatarsal osteotomy (MIS) to correct the hallux valgus. We hypothesized that the two techniques would show significant differences with regard to radiographic and clinical outcomes.

In this study, the open osteotomy group was superior than MIS group in HVA and IMA. It was different from previous studies [24, 26]. The distal part of metatarsal was easier to move laterally to the desired position under open vision. The capsule of the first MTP joint and adjacent ligaments was easy to achieve enough release. However, it was hard to shift the distal part laterally enough due to insufficient release in

Table 2 Radiographic and functional outcomes

| Parameter | Preop | | | Postop | | |
|------------------------------|-----------|-----------|----------------|-----------|-----------|----------------|
| | MIS | Open | <i>p</i> value | MIS | Open | <i>p</i> value |
| HVA, degree | 34.8±4.9 | 33.1±3.3 | 0.409 | 20.4±7.9 | 13.7±7.3 | 0.0009 |
| IMA, degree | 13.0±3.6 | 12.1±2.9 | 0.2504 | 11.4±4.55 | 5.5±3.2 | <0.0001 |
| DMAA, degree | 14.8±8.1 | 15.1±5.5 | 0.8704 | 6.3±4.3 | 8.7±4.6 | 0.0365 |
| The Sgarlato's angle, degree | 18.4±4.5 | 18.8±3.9 | 0.777 | 16.8±4.1 | 16.5±4.1 | 0.821 |
| Length of 1st metatarsal, mm | 59.1±1.9 | 60.2±4.5 | 0.3558 | 53.1±3.4 | 57.7±5.5 | 0.0076 |
| 1,2 gap, mm | 2.9±2.0 | 3.0±2.6 | 0.5295 | 3.0±2.6 | 3.4±1.9 | 0.5922 |
| AOFAS | 44.0±11.9 | 47.6±10.5 | 0.2297 | 90.2±13.3 | 89.5±10.8 | 0.8388 |
| VAS | 7.3±1.7 | 7.1±1.4 | 0.7516 | 1.3±2.0 | 1.2±1.5 | 0.9559 |

**Fig. 5** Histograms showing **A** HVA, **B** IMA, **C** DMAA, and **D** Sgarlato's angle changes before and after surgery

the MIS group. Unlike the open group, it was hard to perform medial capsulorrhaphy in the MIS group.

The comparison of DMAA between the MIS and open surgery group was rarely mentioned in previous studies [9, 26]. The correction of DMAA in the MIS group was superior than the open group in this study. After an oblique osteotomy, the metatarsal head could rotate and shift easily as desired. Thus, the DMAA was easier to be changed compared with open Chevron osteotomy. However, there was a slight shortening of the first metatarsal in MIS group. In the open surgery group, the Chevron osteotomy was stable and could prevent retraction of the metatarsal head. In the

MIS group, the metatarsal head was easy to move and rotate after an oblique osteotomy. It was important to maintain the position of metatarsal head when we moved or rotated it; otherwise, there would be a shortening of the first metatarsal. Although there were differences of HVA, IMA, and DMAA between two groups, the overall functional outcomes were comparable. MIS was as effective as conventional open surgery.

MIS had several advantages. The percutaneous small incision alleviated pain and allowed earlier activities. The oblique osteotomy was long with a large inclination angle, which made osteotomy stable and aided bone union.

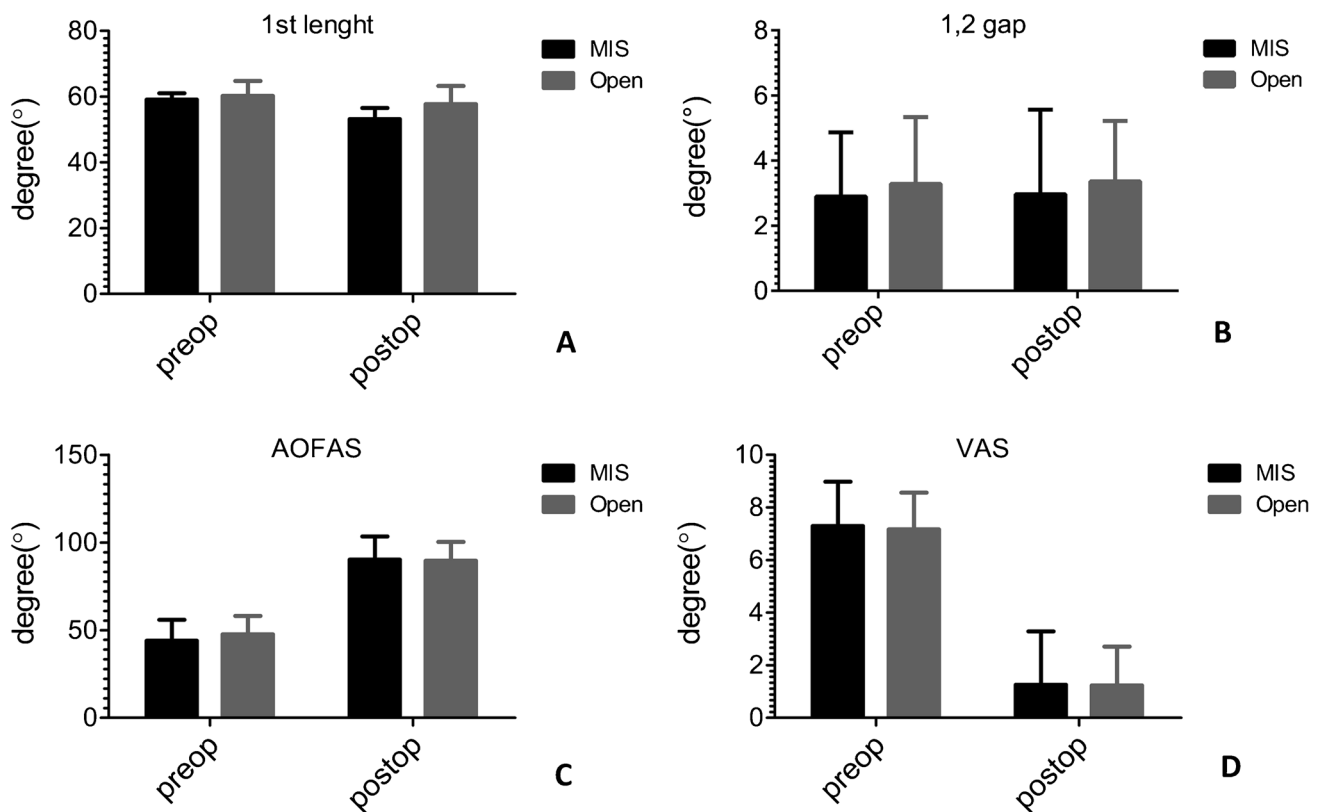


Fig. 6 Histograms showing **A** the length of 1st metatarsal, **B** the distance between the dorsal cortex of 1st and 2nd metatarsal necks, and **C** AOFAS **D** VAS changes before and after surgery

Although the patients in the MIS group achieved similar functional outcomes compared with the open group, and iconographic parameters showed significant improvement in the MIS group, there were some limitations of the MIS. First, it was hard to adequately remove prominent bone ridges of the first metatarsal head through a minimally invasive incision. Some patients still had a residual bunion although the radiographic outcomes were good. The heat of burr may result in thermal damage to the bone. We used cold sterile saline to rinse the burr during the osteotomy to cool the osteotomy site. Unlike the open Chevron osteotomy being directed to the third or fourth metatarsal head as wanted, it was tricky to accurately control the movement direction. So, in some cases, there was a shortening of the first metatarsal to some extent.

There were several limitations of this study. First, the study was performed at one single centre and was based on cases performed by one single senior surgeon. Second, the number of cases was small and the follow-up time was short. Third, the cause and severity of hallux valgus deformity were various. A more precise and specific study is needed. A future study could divide patients into different groups

according to the severity of deformity or different causes in order to explore whether the MIS or open surgery is effective for all patients. Are there any differences of outcomes among different groups? Future studies with larger samples size and longer time follow-up are needed.

Conclusion

The MIS technique was a safe and effective procedure to correct symptomatic hallux valgus deformity. MIS showed advantage in correcting DMAA, although open osteotomies were superior than MIS in HVA and IMA. MIS provided equivalent functional outcomes compared to open surgery.

Author contribution All the authors have made appropriate contributions to this review. Yang Xu designed the study and wrote the manuscript. Xiang-yang Xu revised manuscript and approved article submission. Chang-jun Guo and Xing-chen Li searched and collected the literature.

Data availability Not applicable.

Declarations

Ethical approval Approval for this study was obtained from Ruijin Hospital's institutional review board.

Consent to publish Not applicable.

Consent to participate Written informed consent was obtained from individual or guardian participants.

Competing Interests The authors declare that they have no competing interests.

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