CLINICAL ARTICLE

F-Shaped Osteotomy Combined with Basal Opening Wedge Osteotomy for Severe Hallux Valgus

Chang Li, MD[1], Liang Lu, MD[2], Yu Zhang, MD[3], Qi-cheng Ai-Xin-Jue-Luo, MD[1], Zhen-tang Wang, MD[1], Jun-feng Wang, MD[1]

[1]*Department of Hand and Foot Microsurgery, The Second Affiliated Hospital of Inner Mongolia Medical University, Hohhot, Inner Mongolia,* [2]*Department of Orthopaedics, Anhui Provincial Hospital, Hefei, Anhui and* [3]*Department of Sports Medicine and Adult reconstructive surgery, Drum Tower Hospital, School of Medicine, Nanjing University, Nanjing, Jiangsu, China*

Objective: To evaluate the safety and effectiveness of osteotomy adjacent to the articular surface of the metatarsal head combined with basal opening wedge osteotomy for severe hallux valgus.

Methods: The double osteotomy procedure was carried out in 56 patients (72 feet) with severe hallux valgus deformity, with an average follow-up of 25 months from March 2010 to February 2019. Hallux valgus angle (HVA), distal metatarsal articular angle (DMAA), intermetatarsal angle (IMA), and distal articular set angle (DASA) were measured for all patients *via* weight-bearing anteroposterior (AP) X-ray images. In addition, the American Orthopedic Foot & Ankle Society (AOFAS) scale was used for evaluating the function of the hallux.

Results: The HVA, IMA, and DMAA reduced from 49.30 ± 6.60, 19.33 ± 4.70, and 29.85 ± 10.96 to 13.19 ± 6.10, 5.97 ± 3.13, and 5.63 ± 3.44, respectively ($P < 0.01$). DASA decreased from 4.33 ± 2.34 to 4.08 ± 1.91 and did not show a statistically significant difference ($P = 0.48$). Among the 72 feet, 69 feet healed normally, and 3 feet had bone resorption at the osteotomy edges. No cases of bone sclerosis, bone necrosis, bone nonunion, or ankylosis were observed. On average, the AOFAS score improved from 34.66 ± 12.07 (preoperative) to 88.78 ± 5.73 (postoperative).

Conclusions: The proposed double osteotomy procedure can maintain the match metatarsophalangeal joints without ischemic necrosis of bones, and is demonstrated to be safe, effective, and feasible for correcting severe hallux valgus.

Key words: Basal opening wedge osteotomy; Metatarsal; Metatarsophalangeal; Reverdin osteotomy; Severe hallux valgus

Introduction

Hallux valgus is the most common malformation of the hallux. It directly influences patients' quality of life because of pain, functional disability, and damaged gait patterns[1,2]. Surgical management is the optimal choice for moderate to severe hallux valgus deformities by correcting the deformity, relieving pain, and improving function[3,4]. There are more than 100 operative procedures used for hallux valgus deformity treatment[5,6]. The procedures mainly involve distal osteotomy and soft tissue release. For severe hallux valgus deformities, a proximal osteotomy or arthrodesis procedure has the ability to potentially correct deformity and proximity to the center of rotation of angulation[7,8]. However, proximal osteotomies have higher complication rates, with complications including poor stability, high nonunion, and recurrence[9,10], and are more technically demanding[11–13].

Since the introduction of the Reverdin procedure, many modified procedures have been developed based on

Address for correspondence Chang Li, MD, Department of Hand and Foot Microsurgery, The Second Affiliated Hospital of Inner Mongolia Medical University, No. 1 Yingfang Road, Culture Street, Hui Nationality District, Hohhot, Inner Mongolia Tel: 86-04716351247; Email: 702060437@qq.com
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it[14]. However, distal osteonecrosis resulting from the large osteotomy close to the articular surface of the metatarsal head for patients with severe hallux valgus deformity is one of the most serious complications. It brings considerable physical and psychological burden postoperation[15]. In this study, we propose a double osteotomy procedure for severe hallux valgus deformity, which combines a modified Reverdin osteotomy very close to the articular surface of the metatarsal head with a thin osteocomma in distal artificial surface and basal opening wedge osteotomy. The osteotomies are smaller in the metatarsal head, which retains the intactness of the bone and its nourishing vessels essential to avoid osteonecrosis and promote the bone healing. The purpose of this article are as follows. First, we consider whether this surgical procedure (osteotomy adjacent to the articular surface of the metatarsal head combined with basal opening wedge osteotomy) is feasible in the clinic to treat severe hallux valgus. Is it difficult to perform and it is easy for the articular surface to be damaged due to the short distance between the osteotomy line and the joint surface (e.g. resulting in fractures). Second, using X-ray imaging, we investigate whether the hallux valgus angle is significantly corrected after surgery. We also determine whether the patients are satisfied with the treatment effectiveness from the aspect of the function of the forefoot over a long follow-up period. Third, we analyze whether complications, such as bone resorption, osteonecrosis, and skin necrosis, will occur because the double osteotomy results in a big wound.

Materials and Methods

The study was performed in accordance with the ethical standards of the Second Affiliated Hospital of Inner Mongolia Medical University. After we received clinical approval from our institution, the novel technique was performed on subjects by an experienced surgery.

Inclusion and Exclusion Criteria

Inclusion criteria: (i) patients suffering from preoperative walking pain and bunions after some conservative treatment (orthoses and medician); (ii) strong surgical intention, absolute absence of surgical contraindications, and the ability to tolerate anesthesia; and (iii) severe hallux valgus (hallux valgus angle, HVA≥40° or distal metatarsal articular angle, DMAA≥17°) based on the weight-bearing X-ray[16].

Exclusion criteria: (i) patients with severe or aging-related osteoarthritis on the first metarsophalangeal joint; (ii) unstable tarsometatarsal joint and tarsoptosis; (iii) and serious medical conditions such as cardiovascular disease.

Participants

In our hospital from March 2010 to February 2019, a total of 56 patients (72 feet) were admitted, including 45 females (61 feet) and 11 male (11 feet) patients, with a mean age of 51 years (range, 15–72 years).

The double osteotomy involves the modified Reverdin procedure[14] and basal opening wedge osteotomy, and was performed by the same experienced surgeon. All subjects received a thorough explanation about the risks and benefits of inclusion before participating in this prospective study and gave their written informed consent to publish the data.

Operative Technique

Surgery was performed with a pneumatic ankle tourniquet under spinal anesthesia.

Incision Selection and Osteotomy Location

As shown in Fig. 1, a distal lateral incision with a length of approximately 25 mm was made between the first and second metatarsals, avoiding damage to the dorsal metatarsal artery. A needle tip was used to locate the lateral sesamoid when the tendinous attachment of the adductor halluces muscle and its extension to the lateral metatarsophalangeal joints were exposed. The tendinous attachment of the adductor halluces muscle was then cut off from the lateral sesamoid, avoiding damaging the plantar artery of the metatarsal.

If the lateral sesamoid was dislocated, 1/3–2/3 of the lateral sesamoid was removed using a body oscillating saw to prevent it from blocking the outward migration of the first metatarsal head. However, the lateral sesamoid should not be completely removed, because that could induce the risk of hallux varus.

Management of Osteophytes

Resection of the osteophytes from the medial metatarsal head is shown in Fig. 2. A longitudinal incision with a length of approximately 40 mm was made in the medial metatarsophalangeal joint. Dissection was performed towards the dorsal and plantar part between the superficial and deep fascia until the medial dorsal cutaneous nerves were visible,

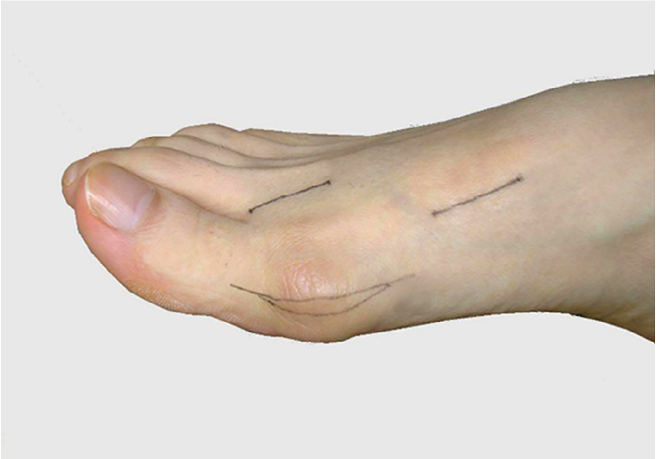

Fig. 1 Incision positions: the proximal line is for metatarsal basal osteotomy; the distal lateral line is for the resection portion of the dislocated sesamoid; and the distal medial line is for varus F-osteotomy.

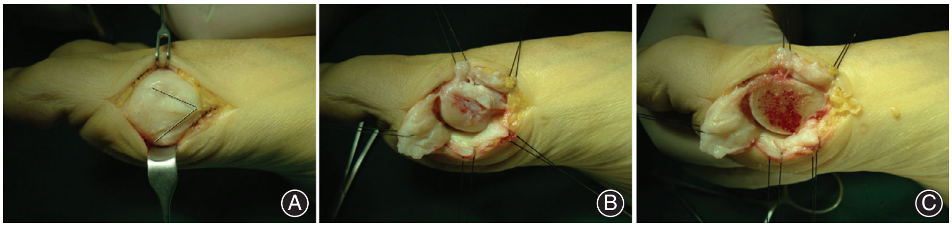

Fig. 2 Resection of the osteophytes from the medial metatarsal head: (A) longitudinal incision of the skin; (B) horizontal and inwards Y-V transposition incision of joint capsule; and (C) resection of osteophytes from the medial metatarsal head.

which were then carefully moved to the dorsal part to expose the articular capsule. A horizontal and inwards Y-V transposition incision was then made on medial capsules. For the proximal Y-shaped incision, the dorsal attachment region of the proximal capsules should be protected for subsequent suturing. A portion of the osteophytes was resected along the sagittal direction, 3 mm away from the medial groove. The resected bone was set aside for subsequent osteotomy.

Detailed Procedure of F-Shaped Osteotomy

F-shaped Osteotomy is shown in Fig. 3. The F-shaped osteotomy surface was composed of a, b, and c planes (Fig. 3D). The a plane was parallel to the distal articular surface of the metatarsal head and was close to the articular surface (4 mm). The b plane was parallel to the plantar articular surface of the metatarsal head. The cross-section of a and b planes is labeled d and the integrity of the junction should be preserved. The c plane was perpendicular to the b plane and was parallel to or constituted an angle with a plane. Four different types of F-osteotomy are described as follows: (i) varus F-osteotomy, where the c plane constituted an angle with the a plane and the bone fragment appearing as a wedge in shape of which the medial thickness was 2–3 mm and the lateral thickness was 0 mm; (ii) shortening F-osteotomy, where the c plane was parallel to the a plane, with a thickness of 2–3 mm; (iii) varus + shortening F-osteotomy, where the varus F-osteotomy and shortening F-osteotomy were superposed and the bone fragment appeared in a wedge shape of which the medial thickness was 3–5 mm and lateral thickness was 2–3 mm; and (iv) outward migration F-osteotomy, where only plane a and b were created (L shape). The articular surface in the above osteotomy was pushed to the lateral side, closer to the second metatarsal.

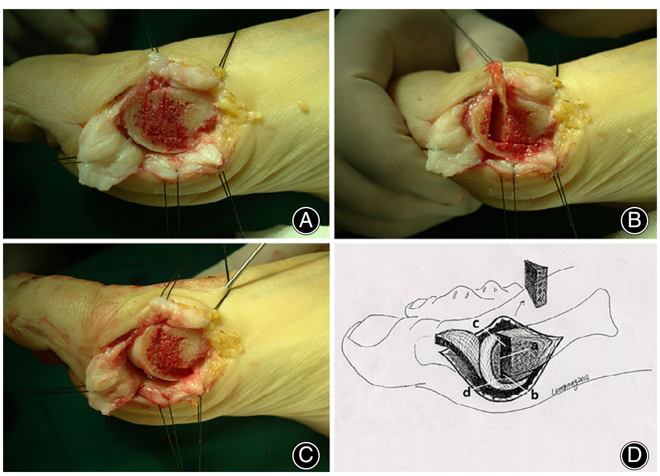

Fig. 3 Varus F-osteotomy on the medial metatarsal head: (A) F-like shape; (B) wedge graft was removed with power saw; (C) metatarsal head was fixed with Kirchner pins after osteotomy; and (D) the schematic diagram of b, plane *a*, *b* and *c*, and junction *d* are labeled.

Managing Metatarsal Basal Osteotomy

A longitudinal straight incision was made at the medial side of the first tarsometatarsal joint, with a length of approximately 30 mm, and was away from the cutaneous dorsalis medialis nerve to expose the capsules. A needle was inserted into the first tarsometatarsal joint to label its location and orientation. Osteotomy was performed parallel to and 4 mm away from the tarsometatarsal articular surface. The depth of the osteotomy was controlled under the X-ray and the lateral cortical bone should not be reached. A Kirchner pin was penetrated into the metatarsal stem and was used to forcibly open up the gap on the metatarsal base widely. Meanwhile, an oscillating saw was used to deepen the gap. Then the gap was opened 4–6 mm with a Kirchner pin. Space was filled by the bone fragments prepared in step 2 and 3. Then the metatarsal was pushed towards the dorsal side to assess the stability of the metatarsal base, where fixation was not necessary if the osteotomy space was stable, while fixation with Kirchner pins was needed for unstable osteotomy space (Fig. 4).

Matching Evaluation of Metatarsophalangeal Joints

The first phalange was twisted medially by hand. Phalange extroversion of 30° should be reached; otherwise, a further shortening F-osteotomy is performed (defined in Step 3 (b)).

Fixation of Articular Surface in Metatarsal Head and Further Matching Evaluation of the Metatarsophalangeal Joints

The articular surface in the metatarsal head was pushed towards the lateral side and a Kirchner pin was traversed to fix the metatarsal head and stem. The excessive bone at the medial metatarsal shaft was removed with the aid of an oscillating saw.

The extent of outward migration of the articular surface of the metatarsal head was dependent on the degree of

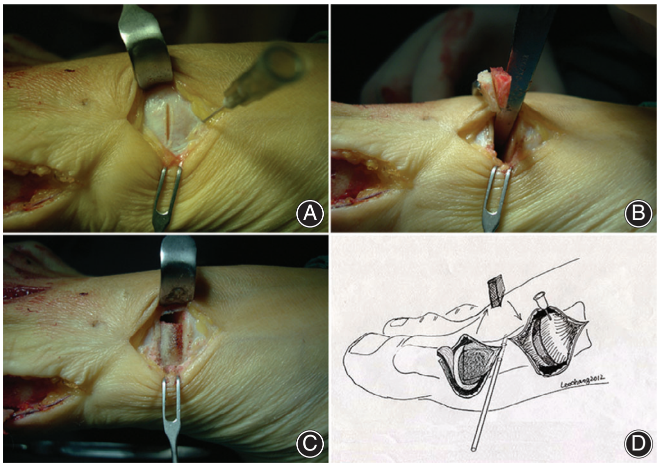

Fig. 4 Metatarsal basal osteotomy and implantation: (A) longitudinal incision on skin and vertical incision on joint capsule; (B) wedge graft from metatarsal head was implanted in metatarsal base; (C) metatarsal base fixation; and (D) schematic diagram of total procedure of metatarsal basal dispose.

basal osteotomy. Migration may not be required if the basal osteotomy is performed properly.

Y-V Tightening of Medial Capsule Articulations Metatarsophalangeae

The phalange was pushed medially, elevated towards dorsiflexion, and twisted as supination, and Y-V transposition was performed. The dorsal capsule was first sutured without affecting the dorsiflexion function. Excessive tightening should be avoided because it might cause varus deformity. Finally, the incision was sutured and a drainage strip was placed, followed by a horizontal compression bandage.

In addition, padded protection was applied for 6 weeks postoperation to ensure the healing of the capsule in the desired position.

Procedure Selection

Routine Seven-Step Method

The magnitude of the metatarsal basal osteotomy was approximately 4–6 mm after maintaining the continuity of lateral cortical bone. Varus F-osteotomy was determined by DMAA, which should be approximately 10° after osteotomy. The angle of the varus F-osteotomy could not be larger than the preoperative DMAA to avoid the risk of varus. The shortening F-osteotomy thickness was determined by the relaxation of the metatarsophalangeal joints where a metatarsal varus of 30° should be achieved by hand after the osteotomy. For superposition of the varus F-osteotomy and shortening F-osteotomy, the thicknesses of the medial and lateral osteotomies were 3–5 mm and 2–3 mm, respectively. The necessity of the outward migration F-osteotomy relied on the relocation of the basal osteotomy. It was outwardly migrated 3–4 mm if there was space in the lateral metatarsal head.

Weil Osteotomy

For cases with claw toe deformity, hallux valgus deformity, dislocation of metatarsophalangeal joints, and metatarsophalangeal arthritis in the two to four toes, the Weil procedure should be applied on the two to four toes[17]. The shortening of the Weil procedure was determined by the length of the first metatarsal in order to balance the first and second metatarsals. In the absence of the deformity described above, Weil osteotomy could still be applied to balance the position between first and second metatarsal head. In our study, there were 15 feet with only second metatarsophalangeal joint dislocation or osteoarthritis and 8 feet with both second and third metatarsophalangeal joint dislocation or osteoarthritis.

After Treatment

Patients began walking indoors with protection 3 days postoperation with firm flat-soled orthopaedic shoes[18]. Two weeks after the surgery, a passive stretching exercise of the metatarsophalangeal joint was given which lasted for 3 months. Kirchner pins were removed 6 weeks after the operation and by then patients started a few outdoor exercises. Patients were allowed to walk normally and wear normal shoes 12 weeks after the surgery.

Outcome Measures

Before and after the procedure, all participators were clinically evaluated with weight-bearing AP X-ray image, and HVA, DMAA, IMA, and DASA were measured by an experienced imaging physician. The AOFAS questionnaires were also assessed before and at the last follow-up after the procedure, and were collected by two experienced doctors. The effectiveness and safety of this double osteotomy surgery procedure were evaluated by comparison of hallux valgus and the score of AOFAS before and after the procedure, respectively. The mean follow-up duration was 25 months (range, 12–32 months). This study is a prospective self-control clinical study.

American Orthopaedic Foot & Ankle Society Scale

The clinical preoperative and last follow-up postoperative evaluations were based on the 100-point AOFAS hallux–metatarso–phalangeal–interphalangeal scale, which includes pain, activity limitation, footwear requirements, metatarsophalangeal (MTP) joint motion, callus related to hallux MTP-interphalangeal (MTP-IP), and alignment[19,20]. The AOFAS score is well-known and widely used for quantitative subjective evaluation on the aspect of foot function in clinic. The chief aim of the double osteotomy is to relieve pain symptoms and to improve the quality of life of patients with severe hallux valgus deformity. Therefore, the contents of the AOFAS are suited to assessing the effectiveness of this surgical procedure.

All patients received instructions from an experienced doctor explaining how to use the AOFAS score to reflect their real condition.

Visual Analogue Scale
Furthermore, all patients were investigated using the visual analogue scale (VAS)[21]. Pain is the most common clinical syndrome influencing normal life activities and mental distress, and being pain free is an important goal of this double osteotomy. The VAS is a simple pain scale for patients to reflect their level of pain. All patients received instructions from an experienced doctor explaining how to use the VAS score to reflect their real level of pain.

Radiographic Measurements
The imaging measurement is the critical indication to assess the degree of deformity correction after this modified double osteotomy procedure. Routine standing anteroposterior X-ray views were obtained under the guidance of an experienced imaging technician before surgery and at final follow-up in accordance with our protocol. The following parameters were evaluated by three experienced foot and ankle surgeons: intermetatarsal angle (IMA: normal value <10°), proximal articular surface angle (DMAA: normal value <6°), hallux valgus angle (HVA: normal value <15°), distal articular set angle (DASA), articular surface congruency, metatarsal index[22], callus formation in anteroposterior view radiographs, and absence of radiolucent lines to determine bone union. The average angle was acquired from three original angles from three experienced surgeons. If they had significantly different opinions on the aspects of the articular surface congruency, metatarsal index, and callus formation, they had a discussion to make a final decision.

Surgical-Related Complications
In addition, any complications were recorded, including infection, resorption at osteotomy edges, resorption below the articular surface, bone sclerosis, necrosis, and nonunion. The assessment of operation-related complications was important to evaluate the feasibility and safety of this surgical procedure because despite better deformity correction of severe hallux valgus compared with the other single osteotomy procedures, the modified double osteotomy resulted in a bigger wound. The complication assessment was also conducted by three experienced foot and ankle surgeons based on the X-ray imaging results. If they initially had three different opinions, they had to a discussion to reach a final conclusion.

Statistical Analysis
Data were analyzed using SPSS 21.0 (SPSS, Chicago, IL, USA). The quantitative data is described as mean ± standard deviation or median (range) for continuous variables and as numbers for categorical measures. For statistical evaluation of the angular values and the clinical scores obtained with the AOFAS scale preoperation and at last follow-up, we used the Student *t*-test. For angular values not normally distributed, we used the Wilcoxon test of signed ranks. The α value was set as 0.05 due to the univariate comparisons before and after surgery. All *P*-values were two-sided, using a significance level of $P < 0.05$.

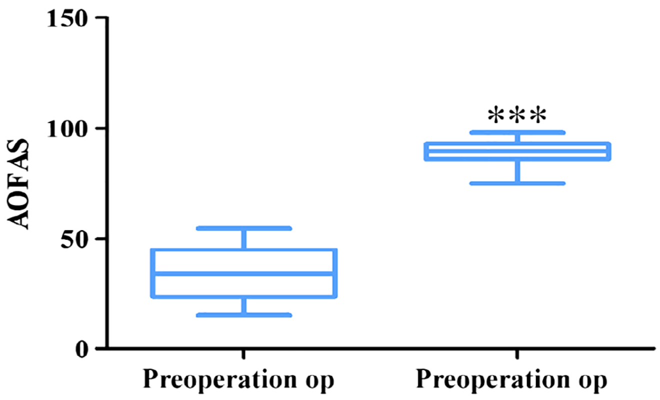

Fig. 5 Graph of statistical analysis of preoperative and postoperative American Orthopaedic Foot & Ankle Society (AOFAS) scores (***,$P < 0.001$).

Results

Patients' Information
Seventy-two feet, with 42 on the right and 30 on the left, of 56 consecutively enrolled patients met the criteria. The median patient age at the time of the surgery was 51 ± 12.5 years (range, 15–72 years). There were 45 women (80.4%) and 11 men (19.6%). All the patients were considered in the analyses.

Clinical Outcomes

American Orthopaedic Foot & Ankle Society Scale
Before the surgical intervention, the mean total AOFAS score of the patients was 34.66 ± 12.07 points (range, 19–55 points). The median of the results was 38 points, and only 4 cases (5.5%) obtained over 50 points. At the last follow-up after the operation, the mean total AOFAS score was significantly improved, to 88.87 ± 5.73 (range, 72–100) ($P < 0.001$) (Fig. 5). Before surgery, almost all patients (98%) had limited ability to participate in daily and recreational activities, and over 80% of those patients returned to normal life activities after the double osteotomy. The percentages of patients who needed modified shoes or a brace and had a symptomatic callus were reduced from 50% and 75% to 0% and 16.7%, respectively. On the aspect of alignment, all patients had poor obvious symptomatic malalignment, and at the last follow-up approximately 70% patients had good hallux alignment. The number of patients with normal or mild restriction had no significant difference before and after osteotomy. Before operation, the patients with moderate or severe MTP

joint motion restriction comprised approximately 12.5% because of severe hallux valgus deformity. However, the number of patients with moderate MTP joint motion restriction increased from 6.25% to 18.75% after surgery. There were no patients with severe MTP joint motion (<30°).

Pain Relieve
All patients suffered from different levels pain and over half of the patients complained about severe pain. At the end of follow-up, the pain was mild and was occasional or absent in 64 feet (88.89%). Only 8 feet (11.11%) had further difficulty or limitation in executing daily and recreational activities. At the final follow-up period, the mean VAS score was 2.52/10 (0–6).

Radiographic Outcomes

Case Study
X-ray results and images for 1 patient with 2 feet with severe HV are shown in Figure 6. In both feet we carried out the modified Reverdin osteotomy and basal opening wedge osteotomy at the same time. After 24 months, the bone had healed and the deformity correction was good. The patient was satisfied with the results (Fig. 6). The follow-up video also demonstrated that the function of her feet had significantly improved (supplement 1) and she could return to normal daily life and work.

Hallux Valgus Angle
The group, consisting of 72 feet, was followed up for a mean duration of 25 months. The hallux valgus angle was reduced from 49.30° ± 6.60° (range, 33.5°–56.5°) before surgery to 13.19° ± 6.10° (range, 0°–24.2°) after surgery ($P < 0.001$), which was close to a normal level.

Distal Metatarsal Articular Angle
The distal metatarsal articular angle was also significantly decreased to 5.63° ± 3.44° (range, 0°–15.3°), from 29.85° ± 10.96° (range, 5.8°–48.9°) ($P < 0.001$).

Intermetatarsal Angle
Satisfactory improvement was achieved in the correction of the intermetatarsal angle, from 19.33° ± 4.70° (range, 15.0°–24.4°) to 5.97° ± 3.13° (range, 2.8°–14.5°) ($P < 0.001$).

Distal Articular Set Angle
However, the distal articular set angle did not show a statistically significant difference from 4.33° ± 2.34° (range, 0°–8.8°) to 4.08° ± 1.91° (range, 2.3°–9.5°) ($P = 0.48$) (Fig. 7).

Complications
Postoperation, 69 feet achieved satisfactory rehabilitation and normal healing. None of the patients had infection, resorption below the articular surface, bone sclerosis, and necrosis and nonunion. Three feet occurred bone resorption at osteotomy edges without the limitation of the joint range of motion, which were possible because of diabetes and elderly patients causing severe osteoporosis and poor blood circulation of the lower limbs.

Fig. 6 The results of a demonstration case preoperation and 24th months postoperation: (A, B) preoperation image and X-ray image of right foot, respectively; (C, D) postoperation X-ray image and picture of right foot, respectively, and preoperation X-ray image of right foot; (E, F) preoperation image and X-ray image of right foot, respectively; and (G, H) postoperation X-ray image and picture of right foot, respectively.

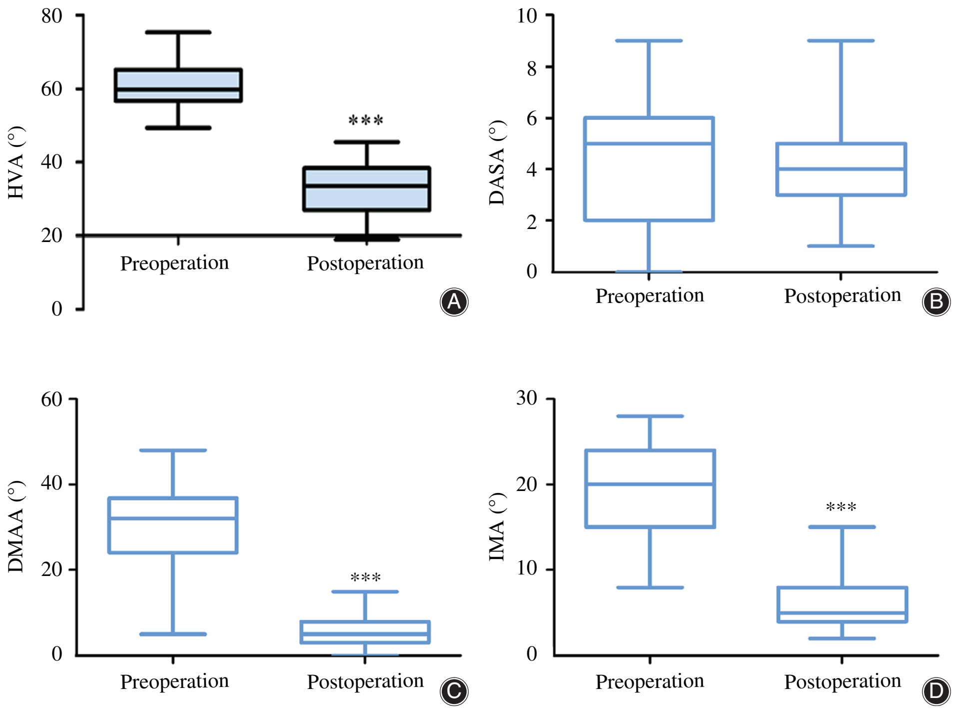

Fig. 7 Graph of statistical analysis of preoperative and postoperative different angular values: (A) hallux valgus (HVA); (B) distal articular set angle (DASA); (C) distal metatarsal articular angle (DMAA); and (D) intermetatarsal angle (IMA) (***,$P < 0.001$).

Discussion

Metatarsal head osteotomy for hallux valgus can be separated into two types. One is varus-dominated osteotomies, such as the Reverdin procedure[14] and the Reverdin–Green procedure[23], while the other type is outward migration-dominated osteotomies, such as Austin[12], Younswick[24] and Cerbert[25]. F-shaped osteotomy herein is conceptually the varus osteotomy adjacent to the articular surface, belonging to the improved Reverdin osteotomy, as shown in Fig. 7. The double osteotomy herein also resembles the Peterson[26] procedure; however, the key difference is the varus osteotomy conducted adjacent to the articular surface.

Previous studies believed that the vascular inlet on the metatarsal head was needed to ensure abundant blood supply;[15] therefore, the osteotomy location should not be close to the articular surface of the metatarsal head, to prevent ischemia. However, there is no stem of vessels inside the metatarsal head and it relies on the sinus in the cancellous bone for blood pressure, leading to a limited transmission range. Therefore, there are a large amount of vessel networks surrounding the cancellous bone providing multiple entrances for the blood to enter the sinus. In traditional procedures, although the osteotomy away from the articular surface could certainly protect the vascular inlet of the bone fragment in the metatarsal head[27], the range of blood supply in the cancellous bone is limited, which leads to inevitable ischemia when the remaining distal metatarsal head is too large. Therefore, we proposed osteotomy adjacent to the articular surface of the metatarsal head, while keeping the remaining portion of the metatarsal head as small as possible. Smaller bone fragment requires less blood supply, thus ensuring quick healing and prevention of ischemia. In this study, osteotomies adjacent to the articular surface were applied on the metatarsal head and base, which increased the stability, reduced ischemia of large bone fragment, and enabled quick healing after osteotomy. The results showed that the osteotomies in the metatarsal head and base quickly healed with less ischemia. No F-osteotomy-related nonunion, necrosis, or articular step-off was found.

The matching between bones includes: (i) matching between metatarsal head and sesamoid (by conducting metatarsal basal osteotomy, outward migration F osteotomy, and partial resection of the sesamoid to sufficiently narrow the first and second metatarsal heads, shorten IMA and relocate the sesamoid); (ii) matching between the first and second metatarsal head (by metatarsal basal osteotomy, shortening F osteotomy, and Weil osteotomy); and (iii) matching of metatarsophalangeal joints (by varus F osteotomy and shortening F osteotomy).

The soft tissue balance may include the following: shortening F-osteotomy; partial resection of sesamoid and incision of adductor halluces muscle can effectively reduce the tension on lateral metatarsophalangeal joints slacken the lateral joint capsule; and the tightening capsule in the medial metatarsophalangeal joints can increase the tension on the medial side. However, excessive slackness on the lateral side, excessive sesamoid resection and medial osteophyte resection, as well as excessive tightening of the medial capsule can induce hallux varus. Meanwhile, excessive varus F osteotomy and excessive shortening F osteotomy may lead to loss of forward support of the metatarsal heads, which will also cause the hallux varus.

There are associations among multiple osteotomy methods. First, the outward migration F-osteotomy was able to compensate for the insufficient migration amplitude of the metatarsal head in basal osteotomy. Second, the varus F-osteotomy is needed to correct the increased DMAA. In addition, shortening F-osteotomy is needed to correct the lengthening of the first metatarsal bone after open metatarsal basal osteotomy.

In this study, a very effective method that opens the medial metatarsal base by traversing a Kirchner pin across the first metatarsal shaft was proposed, which can avoid the risk of fracture of the lateral metatarsal base and increase the opening magnitude of the osteotomy. Our proposed basal osteotomy also maintains the stability of the metatarsal base after bone implantation without the necessity of internal fixation.

Matching of metatarsophalangeal joints before the fixation of the metatarsal head is crucial. A phalangeal varus approximately 30° should be attainable by hand. Further shortening F-osteotomy should be conducted if the matching is not satisfactory. Of course, the length balance of the first and second metatarsal bones should be taken into account, where an excessive shortening F-osteotomy may be harmful, and sometimes the Weil osteotomy will be needed to shorten the second metatarsal head.

The varus F-osteotomy angle is determined by the DMAA, which should achieve an angle of 10° after the F-osteotomy. The process should be closely monitored *via* a C-arm as excessive varus angle may cause varus deformity.

There are some limitations to the present study, including the small sample size of 72 feet from 56 patients and the short duration of 25 months' follow-up to evaluate the modified technique. Nonetheless, such limitations are common in the foot and ankle surgery literature. Furthermore, a control group to compare the advantages and disadvantages of our method is lacking in this study. Hence, we believe that long-term follow-ups with a larger sample and randomized controlled clinical trials are necessary for further study to evaluate the effectiveness and satisfaction of modified Reverdin osteotomy combined with basal opening wedge osteotomy for severe hallux valgus.

Conclusions

All data from this study, including the clinical and radiological results, lead to the conclusion that the modified Reverdin osteotomy combined with basal opening wedge osteotomy for severe hallux valgus provides a significant reduction of IMA and improves the quality of life for patients. The prominent advantages of the double osteotomy procedure are achieving good joint matching between metatarsal head and sesamoid, length matching between the first and second metatarsal head, and the strength balance of metatarsophalangeal joints. In addition, intracapsular osteotomy adjacent to the articular surface of the metatarsal head protects many sinusoids from damage so that a small piece of distal bone is unlikely to induce severe ischemic necrosis. In addition, basal opening wedge osteotomy is firmly fixed using the wedge bone block removed from the intracapsular osteotomy without any bone implants, which is helpful for increasing the correction of severe deformity and reducing the cost of surgery. It is a good alternative to opt for in the treatment of severe hallux valgus. Studies with a large sample size and longer follow-up duration could shed more light on this procedure, which needs further investigation.

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