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Importance of postoperative sesamoid reduction on the outcomes of proximal chevron osteotomy for moderate to severe hallux valgus deformity

Keun-Bae Lee, Myung-Sun Kim, Kyung-Soon Park, Gun-Woo Lee*

Department of Orthopedic Surgery, Chonnam National University Hospital, Gwangju, Republic of Korea

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ABSTRACT

Background: The purpose of this study was to compare the clinical and radiographic outcomes between feet with or without postoperative sesamoid reduction of proximal metatarsal chevron osteotomy for moderate to severe hallux valgus deformity.
Methods: All of 110 feet were allocated into two groups (reduction group; 66 feet, non-reduction group; 44 feet) according to the reduction status of sesamoid at 6 months after surgery. The clinical and radiographic results of the two groups were compared preoperatively, 6 months follow-up, and at last follow-up.
Results: The overall improvement in clinical outcomes was similar in both groups at average 4-year follow-up. However, the radiographic outcomes and recurrence rate were significantly worse in the sesamoid non-reduction group.
Conclusions: Our results suggested that postoperative incomplete reduction of sesamoid may increase a risk for the recurrence of hallux valgus deformity.

1. Introduction

Proximal metatarsal chevron osteotomy combined with a distal soft tissue procedure has been widely used to correct moderate to severe hallux valgus deformities. Previous studies have reported excellent outcomes with this procedure and high rates of patient satisfaction [1–6]. However, there may be recurrence of the hallux valgus deformity after proximal metatarsal chevron osteotomy. The recurrence of the hallux valgus deformity is due to various reasons, including incomplete release of the adductor hallucis tendon, insufficient imbrication of the medial capsule, increased distal metatarsal articular angle, insufficient correction of the metatarsus primus varus, excessive first ray mobility, and incomplete reduction of the sesamoid [7,8].

Among these factors, the postoperative incomplete reduction of the sesamoid is one of the important issues in the recurrence after hallux valgus correction. Several studies have analyzed the relationship between the postoperative position of the sesamoid and recurrence of the hallux valgus deformity [9–12]. One study reported that postoperative incomplete reduction of the sesamoid can be a risk factor for the recurrence of hallux valgus deformity [10]. On the other hand, other studies reported that improvement in sesamoid position was not associated with patient satisfaction [11,12]. Accordingly, there is still little consensus concerning whether incomplete reduction of the sesamoid after surgery is a risk factor for the progression or recurrence of the hallux valgus deformity and the correlation between incomplete reduction of the sesamoid and outcomes.

We hypothesized that even though hallux valgus deformity was corrected, postoperative incomplete reduction of the sesamoid position can result in higher recurrence of hallux valgus and poor outcomes. The purpose of the present study was to compare the clinical and radiographic outcomes of two groups with or without postoperative sesamoid reduction in patients who underwent proximal metatarsal chevron osteotomy combined with a distal soft tissue procedure, and to know whether the intraoperative sesamoid reduction is necessary or not.

2. Methods

2.1. Patients

We obtained approval from our institutional review board, and all patients granted their informed consent. The study was carried

* Corresponding author at: Department of Orthopaedic Surgery, Chonnam National University Hospital, 42 Jebongro, Donggu, Gwangju 61469, Republic of Korea.
E-mail address: kbleeos@chonnam.ac.kr (G.-W. Lee).

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out in accordance with the World Medical Association Declarationof Helsinki. From January 2008 to December 2014, 130 adult female patients (159 feet), with symptomatic moderate to severe hallux valgus deformity, underwent proximal metatarsal chevron osteotomy combined with a distal soft tissue procedure. All procedures were performed by a single surgeon. Indications for this procedure were symptomatic painful hallux valgus deformity, difficulty in wearing shoes, no previous hallux valgus surgery, a preoperative hallux valgus angle of ≥20° or preoperative first-second intermetatarsal angle of ≥14° and an incongruent first metatarsophalangeal joint. Conservative treatment, including shoe-wear modification, nonsteroidal anti-inflammatory medications, and arch supports, had failed for all patients. Twenty patients (33 feet) with other pathologies (symptomatic posterior tibial tendon dysfunction, gastrocnemius contracture, inflammatory arthropathy, ankle deformity, or midfoot arthritis) or post-traumatic hallux valgus, and patients that underwent revision surgery, likely to confuse outcome assessments, were excluded from the study. Eleven patients (16 feet) without adequate follow-up were additionally excluded (Fig. 1). The remaining 99 patients (110 feet) with a mean age of 54.2 years (range, 36–77) and followed-up for at least 24 months were included and constituted the study cohort.

2.2. Operative technique

Patients underwent surgery performed by a single surgeon under general or spinal anesthesia with a pneumatic thigh tourniquet. For the proximal chevron osteotomy, standard medial incision was used starting over the proximal phalanx and continuing proximally along the medial border of the metatarsal, ending at the metatarsocuneiform joint. Medial joint capsule was incised in the middle. A Kirschner (K-) wire was then placed 10 mm distal to the metatarsocuneiform joint to act as a guide to the proximal apex of the reverse chevron osteotomy. Then, 60° chevron osteotomy was performed. Correction was achieved by a combination of lateral displacement and tilt of the distal fragment. The osteotomy site was fixed with two medially placed 1.6 mm K-wires which ran from proximal to distal and from medial to lateral across the osteotomy and into the metatarsal head. Any medial overhanging edge at the osteotomy site was excised, and filled medial gap with excised bone fragment.

The distal soft tissue procedure was performed using dorsal first web-space approach. A 3-cm dorsal longitudinal incision was centered on the first intermetatarsal web space. The distal soft tissue procedure included release of the adductor hallucis tendon from its attachment at the base of the proximal phalanx and fibular sesamoid, detachment of the fibular sesamoid-metatarsal ligament, transection of the transverse metatarsal ligament, perforation of the lateral first metatarsophalangeal joint capsule with several puncture wounds, excision of the medial eminence, and plication of the medial joint capsule.

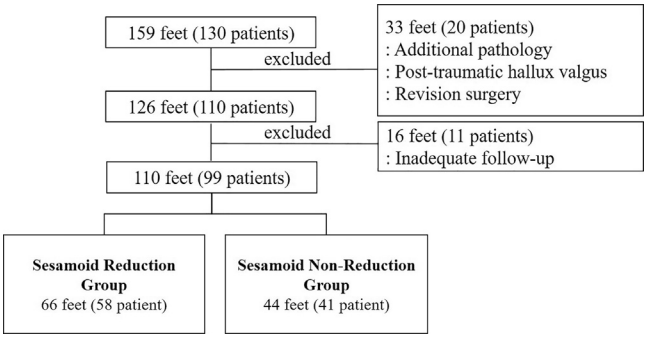

Fig. 1. CONSORT (Consolidated Standards of Reporting Trials) flow diagram of this study.

After surgery, a gauze dressing was applied, taking care not to pronate the toe or to force it into varus. Patients were allowed to walk using a postoperative shoe and bearing weight on the heel and lateral aspect of the foot. Early passive metatarsophalangeal stretching exercise was encouraged. The K-wires were usually removed in an outpatient checkup six to eight weeks after surgery, after which patients were allowed to wear a soft shoe [4,13].

2.3. Radiographic outcome evaluations

Anteroposterior and lateral weight bearing radiographs of the foot were taken at 6 months after surgery and at the final follow-up visit to measure the hallux valgus angle, first-second intermetatarsal angle, and tibial sesamoid position. The hallux valgus angle was defined as the angle formed by the intersection of the diaphyseal axis of the proximal phalanx of the great toe and the longitudinal axis of the first metatarsal. The angle was determined by connecting the center of the first metatarsal head and the center of the proximal articular surface. The first-second intermetatarsal angle was defined as the angle subtended by lines bisecting the longitudinal axes of the first and second metatarsals. We used this method based on Shima et al. which reported a high intraobserver and interobserver reproducibility and showed ≥80% agreement for measuring the preoperative and postoperative hallux valgus and intermetatarsal angles [14].

In all cases, the sesamoid was displaced laterally. These 110 feet were divided into two groups depending on the status of sesamoid reduction at postoperative 6 months follow-up (Table 1). The position of the tibial sesamoid in relation to a line drawn along the longitudinal axis of the first metatarsal on the dorsoplantar weight-bearing radiograph was classified as grade 0–3, where a normal position was classified as grade 0 (Fig. 2). The most severe lateral subluxation, whereby the tibial sesamoid was completely displaced laterally beyond the longitudinal axis of the first metatarsal, was classified as grade 3 [15]. We considered that grades 0 or 1 as the reduction group and grades 2 or 3 as the non-reduction group. All radiographic measurements were measured accurately using the Picture Archiving and Communication System (PACS version 5.4; Marotech, Seoul, Korea) by two investigators who were not involved in the surgical treatment.

2.4. Clinical outcome evaluations

The American Orthopaedic Foot and Ankle Society (AOFAS) hallux metatarsophalangeal-interphalangeal score and the patient satisfaction were obtained preoperatively and at the final follow-up [16]. The 100-point AOFAS scoring system combines subjective and objective data to evaluate clinical parameters; points are allocated as follows, pain (40 points), function (45 points), and alignment (15 points). To evaluate patients' subjective satisfaction, we asked patients their opinions concerning the procedure results. Responses were categorized as "very satisfied", "satisfied", "dissatisfied", or "very dissatisfied". The reliability and validity of this patient satisfaction scale are unknown.

2.5. Statistical analysis

The estimated sample size was based on the hallux valgus angle, which was the primary outcome variable in the previous study [10]. A minimum of 37 patients was needed per group to ensure 80% power. The paired t-test was used to assess the intra-group differences of clinical and radiographic results before and after surgery. The independent t-test was used to determine the

Table 1
Patient demographics of two groups with or without postoperative sesamoid reduction.[a]

	Reduction group (n = 66)	Non-reduction group (n = 44)	*P* value[b]
Number of feet (patient)	66 (58)	44 (41)	0.631
Right/left	32/34	23/21	0.056
DM, n (%)	8 (11.1)	6 (9.5)	0.746
Age (years)	54.2 ± 8.14	53.8 ± 9.7	0.134
Symptom duration (years)	10.1 ± 11.2	9.6 ± 6.5	0.175
Follow-up duration (months)	52.4 ± 17.8	50.5 ± 16.5	0.789

DM: diabetes mellitus.
[a] Values are expressed as mean ± standard deviation for the continuous variables.
[b] Independent t-test. The *P* values are of inter-group comparisons. Significance was accepted for *P* values of <0.05.

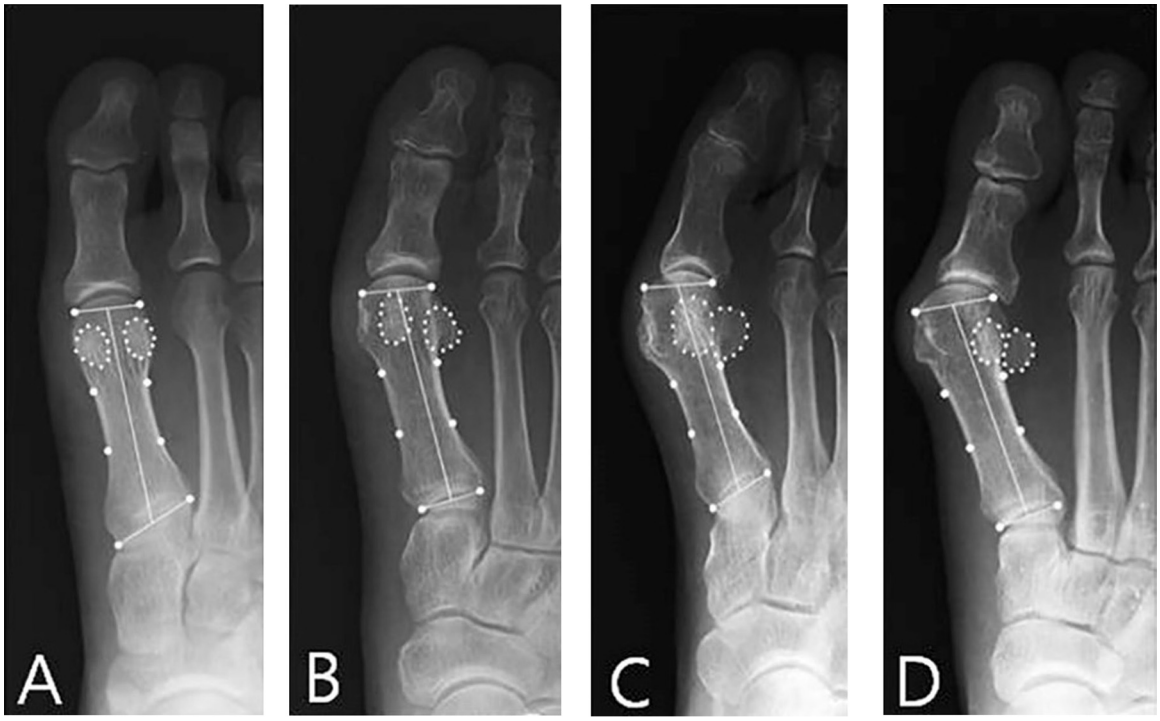

Fig. 2. The position of tibial sesamoid was classified as graded 0–3, according to its position relative to the longitudinal axis of the first metatarsal on the dorsoplantar weight-bearing radiograph. (a) Grade 0, normal position. (b) Grade 1, less than 50% of the tibial sesamoid crossed reference line. (c) Grade 2, more than 50% of the tibial sesamoid crossed reference line. (d) Grade 3, completely displaced laterally.

significance of inter-group differences in patient's demographics, hallux valgus angle, and first-second intermetatarsal angle. The Mann–Whitney U-test was used to determine the significance of inter-group differences in AOFAS score, and the patient satisfaction. Pearson's chi-squared test and Fisher exact test was performed to determine the significance of inter-group differences in rates of complications. Statistical significance was defined as $P < 0.05$ and the statistical analysis was independently reviewed by a statistician.

3. Results

Fifty-eight patients (66 feet, age 54.2 ± 8.14 years) in the reduction group and 41 patients (44 feet, age 53.8 ± 9.7 years) in the non-reduction group were included for this study.

The mean AOFAS hallux metatarsophalangeal-interphalangeal scores were evaluated at preoperative, postoperative 6 months follow-up, and final follow-up for both groups and are shown in Table 2. The following mean scores in both groups were not significantly different at average 4-year follow-up ($P = 0.874$).

The results of patient satisfaction survey revealed 95.4% of satisfaction in the reduction group and 93.2% in the non-reduction group. No patients in both groups were very dissatisfied with surgical result. Patient satisfaction was not significantly different between the two groups ($P = 0.481$).

The radiographic results are shown in Table 3. Corrections of the hallux valgus angle and first-second intermetatarsal angle were significantly achieved in both groups at postoperative 6 months and final follow-up. The hallux valgus angle ($P = 0.005$) and the intermetatarsal angle ($P = 0.007$) in the sesamoid non-reduction group were increased more than those of the reduction group during average 4-year follow-up (Fig. 3). The average preoperative hallux valgus angle (39.0 ± 6.3 and 36.1 ± 7.8) and intermetatarsal angle (18.5 ± 4.0 and 17.2 ± 2.9) in the patients with or without recurrence showed no significant difference, respectively ($P = 0.089$ and $P = 0.138$) (Table 5).

The distributions of the tibial sesamoid position in the two groups with or without postoperative sesamoid reduction are shown in Table 4 (Figs. 4 and 5).

In complications, there was significant intergroup differences ($P = 0.003$). Hallux valgus deformity recurred (a hallux valgus angle of 20° or greater) in 2 feet in reduction group and 9 feet in non-reduction group, and this prevalence showed significant difference

Table 2
Comparison of clinical outcomes between the two groups with or without postoperative sesamoid reduction after proximal chevron osteotomy.[a]

	Reduction group (n = 66)	Non-reduction group (n = 44)	*P* value[b]
AOFAS score (total)			
Preoperative	55.7 ± 8.7 (39–75)	53.8 ± 10.3 (24–75)	0.154
Initial follow-up[c]	84.3 ± 7.8 (70–100)	82.6 ± 6.8 (67–100)	0.421
Final follow-up	92.0 ± 8.7 (70–100)	91.4 ± 8.1 (73–100)	0.874
AOFAS score (pain)			
Preoperative	21.1 ± 3.1 (20–30)	21.5 ± 3.2 (20–30)	0.941
Initial follow-up	32.7 ± 4.2 (20–40)	32.5 ± 4.8 (20–40)	0.576
Final follow-up	37.5 ± 4.8 (20–40)	37.1 ± 4.5 (30–40)	0.698
AOFAS score (function)			
Preoperative	32.1 ± 5.3 (19–40)	30.2 ± 7.5 (4–40)	0.334
Initial follow-up	38.9 ± 4.2 (24–45)	38.2 ± 4.8 (27–45)	0.418
Final follow-up	40.7 ± 4.8 (29–50)	40.3 ± 5.0 (24–45)	0.895
AOFAS score (alignment)			
Preoperative	2.5 ± 2.7 (0–8)	2.1 ± 2.3 (0–8)	0.162
Initial follow-up	12.7 ± 3.2 (8–15)	11.9 ± 2.8 (8–15)	0.336
Final follow-up	13.8 ± 2.7 (8–15)	14.0 ± 2.2 (8–15)	0.378

AOFAS score: American Orthopaedic Foot and Ankle Society hallux metatarsophalangeal-interphalangeal score.
[a] Values are presented as mean ± standard deviation and ranges in parentheses.
[b] Mann–Whitney U-test. The *P* values shown are for inter-group comparisons. Significance was accepted for *P* values of <0.05.
[c] Initial follow-up period indicated postoperative 6 months follow-up.

Table 3
Comparison of radiographic outcomes between the two groups with or without postoperative sesamoid reduction after proximal chevron osteotomy.[a]

	Reduction group (n = 66)	Non-reduction group (n = 44)	*P* value[b]
Hallux valgus angle (°)			
Preoperative	36.7 ± 7.9 (23.6–58.5)	35.5 ± 6.9 (22.3–48.0)	0.598
Initial follow-up[c]	11.0 ± 3.8 (3.2–17.8)	12.2 ± 4.4 (2.1–18.7)	0.303
Final follow-up	12.1 ± 4.5 (−2.9 to 24.3)	14.6 ± 6.5 (−5.3 to 33.0)	0.005
P value[d]	0.001	0.001	
Intermetatarsal angle (°)			
Preoperative	17.4 ± 2.7 (11.7–22.6)	17.1 ± 3.2 (11.2–23.0)	0.785
Initial follow-up	7.3 ± 2.7 (0.8–11.6)	7.6 ± 2.7 (3.2–13.5)	0.670
Final follow-up	8.4 ± 2.4 (3.5–13.6)	10.4 ± 2.6 (1.9–23.0)	0.007
P value	0.001	0.001	

[a] Values are expressed as mean ± standard deviation and ranges in parentheses.
[b] Independent t-test. The *P* values shown are for inter-group comparisons. Significance was accepted for *P* values of <0.05.
[c] Initial follow-up period indicated postoperative 6 months follow-up.
[d] Paired t-test. The *P* values shown area for intra-group comparisons of the results between preoperative and final follow-up. Significance was accepted for *P* values of <0.05.

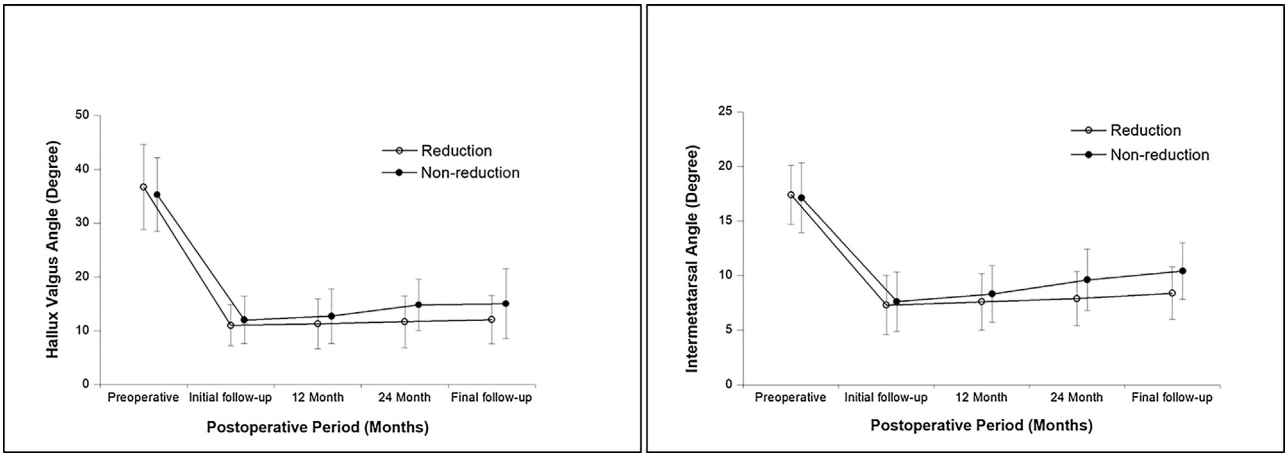

Fig. 3. Graphs showing the change in the hallux valgus angle and intermetatarsal angle over time in the reduction group and non-reduction group. Significant corrections of the hallux valgus angle, and first-second intermetatarsal angle were achieved in both groups after surgery ($P < 0.05$).

Table 4
Distribution of the tibial sesamoid position in the two groups with or without postoperative sesamoid reduction after proximal chevron osteotomy.[a]

Grade[b]	Reduction group (n = 66)			Non-reduction group (n = 44)		
	Preoperative	Initial follow-up[c]	Final follow-up	Preoperative	Initial follow-up[c]	Final follow-up
0	0	25 (38%)	21 (32%)	0	0	0
1	0	41 (62%)	45 (68%)	0	0	0
2	16 (24%)	0	0	6 (14%)	37 (84%)	34 (77%)
3	50 (76%)	0	0	38 (86%)	7 (16%)	10 (23%)

[a] Values are expressed as number and percentage in parentheses.
[b] Grade of sesamoid position: tibial sesamoid in relation to the longitudinal axis of the first metatarsal bone: 0, normal position; 1, less than 50% of the tibial sesamoid crossed reference line; 2, more than 50% of the tibial sesamoid crossed reference line; 3, completely displaced laterally.
[c] Initial follow-up period indicated postoperative 6 months follow-up.

Table 5
Comparison of radiographic outcomes between the two groups with or without recurrence after proximal chevron osteotomy.[a]

	No recurrence group (n = 99)	Recurrence group (n = 11)	*P* value[b]
Hallux valgus angle (°)			
Preoperative	36.1 ± 7.8 (22.3–58.5)	39.0 ± 6.3 (28.2–46.1)	0.089
Initial follow-up[c]	11.0 ± 4.0 (2.1–18.7)	13.3 ± 6.6 (7.4–16.6)	0.025
Final follow-up	11.3 ± 5.5 (−5.3 to 18.2)	24.8 ± 3.1 (22.0–33.0)	0.001
Intermetatarsal angle (°)			
Preoperative	17.2 ± 2.9 (11.2–23.0)	18.5 ± 4.0 (12.7–22.6)	0.138
Initial follow-up	7.3 ± 2.7 (0.8–13.5)	7.6 ± 3.0 (3.4–12.5)	0.426
Final follow-up	8.9 ± 2.6 (1.9–13.9)	11.3 ± 4.9 (5.3–23.0)	0.046

[a] Values are expressed as mean ± standard deviation and ranges in parentheses.
[b] Mann–Whitney U-test. The *P* values shown are for inter-group comparisons. Significance was accepted for *P* values of <0.05.
[c] Initial follow-up period indicated postoperative 6 months follow-up.

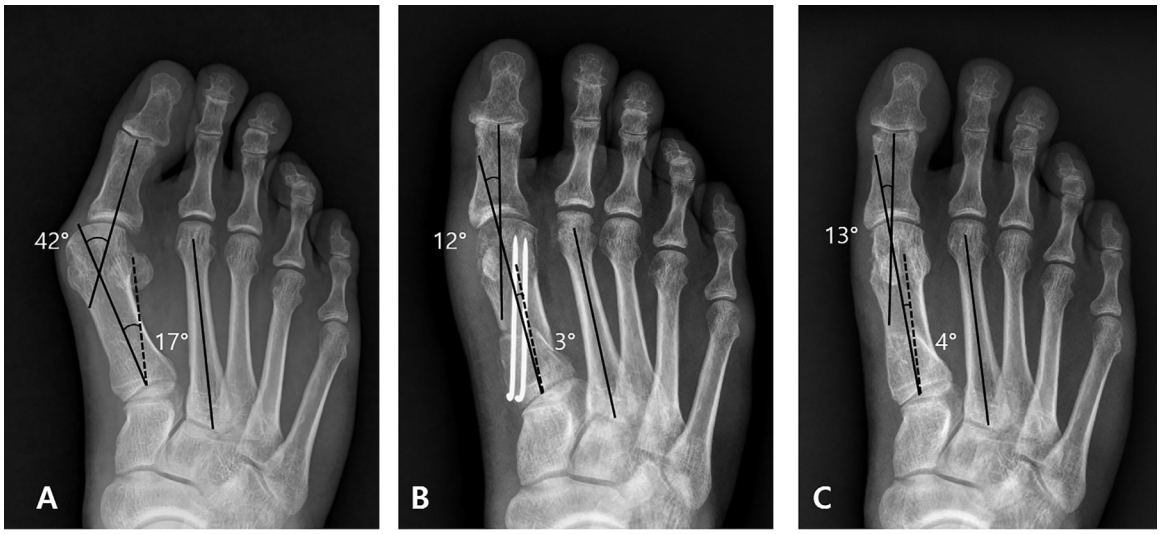

Fig. 4. The weight-bearing radiographs of a 63-year-old woman with a severe hallux valgus deformity who underwent proximal chevron osteotomy with distal soft tissue procedure. (a) Preoperative radiograph showed 42.0° of hallux valgus angle, 17.4° of intermetatarsal angle, and grade 3 position of sesamoid. (b) Initial postoperative 6 months follow-up radiograph showed good correction such as hallux valgus angle 12.2°, intermetatarsal angle 3.3°, and grade 0 position of sesamoid. (c) Final follow-up radiograph of 49 months showed good alignment with a hallux valgus angle 13.0° and intermetatarsal angle 4.1° and maintained sesamoid reduction status.

(*P* = 0.006). In addition, one case of hallux varus deformity was reported in each group. One foot in each group complained of numbness at the dorsomedial aspect of the great toe, and the symptom gradually improved. There were three cases with wound problem (one foot in reduction group, two feet in non-reduction group) and all feet responded to local wound care and antibiotics. The majority of patients in both groups experienced a mild reduction in first metatarsophalangeal joint motion postoperatively, but no foot was symptomatic. There was one case of dorsiflexed malunion in each group. There was no case of nonunion, deep infection, and first metatarsophalangeal joint arthrosis in either group.

4. Discussion

The function of the sesamoid bones is to protect the tendon of flexor hallucis from repeated trauma, act as a pulley to increase the mechanical advantage of the flexor hallucis brevis muscle, and

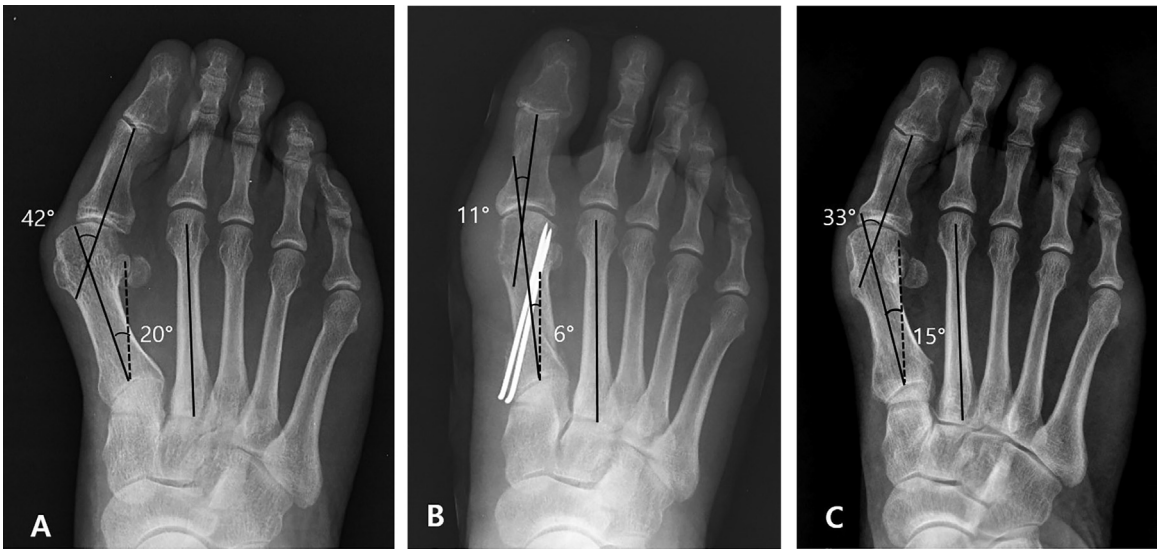

Fig. 5. The weight-bearing radiographs of a 58-year-old woman with a severe hallux valgus deformity who underwent proximal chevron osteotomy with distal soft tissue procedure. (a) Preoperative radiograph showed 42.3° of hallux valgus angle, 20.2° of intermetatarsal angle, and grade 3 position of sesamoid. (b) Initial postoperative 6 months follow-up radiograph showed good correction such as hallux valgus angle 11.0°, intermetatarsal angle 5.8°, and grade 2 position of sesamoid. (c) Final follow-up radiograph of 72 months showed recurrence with a hallux valgus angle 33.2° and intermetatarsal angle 15.3° and non-reduction status of sesamoid.

raise the first metatarsal head higher than the other metatarsal heads so it can bear more weight during stance and gait [16,17].

The AOFAS clinical rating system, and Hardy and Clapham classification systems are the two main classifications for evaluating the radiographic parameters of sesamoid position [16,18]. Both systems were devised by using a reference line bisecting the first metatarsal shaft. AOFAS is a four- grade classification system, while the Hardy and Clapham system uses seven-grades. The AOFAS system defines grade 2 and 3 as being displaced while the Hardy and Clapham defines displacement as grade V. We chose to use the AOFAS grading system because it is simpler and clearer in describing sesamoid position.

Laterally displaced sesamoid is highly correlated with the severity of the hallux valgus deformity. While the first metatarsal translates medially, the position of sesamoid does not change initially due to the tethering effect of the transverse metatarsal ligament and the adductor halluces tendon. However, as the hallux valgus and metatarsus primus varus deformities progress more, sesamoid translated laterally and dorsally relative to the first metatarsal head [17,19,20].

This uncorrected status of sesamoid may be related to recurrence of hallux valgus deformity. As the deformity progresses, sesamoid translate and rotate laterally. According to position change of sesamoid, the flexor halluces tendons follow, and hallux valgus deformity becomes severe as the lateralizing vector is accentuated [17,19–21]. So, laterally displaced sesamoid have been thought to be relevant to the progression or postoperative recurrence of the hallux valgus deformity [20,22].

Several studies demonstrated incomplete reduction of the sesamoid as an important factor in the recurrence of hallux valgus deformity [10–12,21–25]. Okuda et al. reported that the non-reduction group's average hallux valgus and intermetatarsal angles at the time of the final follow-up after proximal metatarsal osteotomy were significantly greater than those at the time of the early follow-up [10]. They suggested that postoperative incomplete reduction of the sesamoid can be a risk factor for the recurrence of hallux valgus. Coughlin also emphasized that the importance of sesamoid reduction for hallux valgus correction and non-reduced sesamoid may create a risk for recurrent deformity [23].

On the other hand, Woo et al. reported radiologic outcome after lateral soft tissue release on sesamoid position, showing no effect in medial shift or reduction of the sesamoid position [25]. Huang et al. also described that the majority of sesamoid correction was not correlated with medial capsular plication, but the intermetatarsal angle correction [22]. In addition, Esemenli et al. reported that sesamoid reduction could be achieved by only shifting of the metatarsal head without adductor tendon release. So, they suggested that the reduction of sesamoid could not be obtained by direct reduction, but due to the lateral shifting of the metatarsal head indirectly [21].

There are still debates on that sesamoid reduction is a risk factor of recurrence of hallux valgus. In this study, the radiographic outcomes and recurrence rate were significantly worse in sesamoid non-reduction group. This means that if the sesamoid reduction is insufficient, the hallux valgus and intermetatarsal angles may increase over time, which can ultimately lead to radiographic poor outcomes of hallux valgus.

While there had been several reports providing radiographic evidence of the relationship between incomplete sesamoid reduction and recurrence, there were no studies using functional outcomes. So, we compared the clinical outcomes of the two groups depending on the sesamoid reduction and found no significant differences between groups. It seems that the correction of hallux valgus deformity has a greater influence in reducing pain and increasing cosmetic satisfaction than the completeness of sesamoid reduction. However, the lack of a significant difference in clinical outcomes between the two groups does not imply that sesamoid reduction is unnecessary. On the contrary, since incomplete sesamoid reduction is more likely to lead to the recurrence of hallux valgus, if and when recurrence occurs, clinical outcomes can worsen over long-term follow-up.

There are some limitations to this study. First, this study was conducted retrospectively, thus radiographs were not precisely controlled. It is possible that slight variability of foot positioning and rotation influenced assessments the sesamoid position. Second, since patients have been recruited from a single hospital, inherent selection and observer bias may exist.

5. Conclusion

In conclusion, the radiographic outcomes and recurrence rate were significantly worse in the sesamoid non-reduction group

despite a similar clinical outcomes and patient satisfaction between the two groups. Our results suggested that postoperative incomplete reduction of sesamoid may increase a risk for the recurrence of hallux valgus.

Conflict of interest

None.

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Not applicable.

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