Arthroscopic Autologous Bone Grafting for Hallux Sesamoid Fracture Nonunion Results in a High Rate of Complete Resolution
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**Purpose:** To review the outcomes of patients with hallux sesamoid fracture nonunion who underwent arthroscopic autologous bone grafting. **Methods:** Medical records of patients who underwent surgery between July 2017 and April 2020 were reviewed. The inclusion criterion was 2 years or more of follow-up. The exclusion criterion was less than 2 years of follow-up. Outcomes were assessed using the visual analog scale (VAS) for pain and the Japanese Society for Surgery of the Foot (JSSF) score. Improvements after surgery were analyzed using the Wilcoxon signed-rank test. **Results:** Eleven patients (3 women and 8 men) were enrolled. The mean age was 18.6 years (standard deviation [SD] ± 10.3 years), and the mean body mass index was 21.9 kg/m² (SD ± 2.5 kg/m²). The mean follow-up duration was 3.2 years (SD ± 0.8 years). One patient had fracture nonunion in the fibular sesamoid and a hypoplastic tibial sesamoid. Another patient had fracture nonunion in the distal part of the congenital bipartite sesamoid. The other patients had fracture nonunion in the normal tibial sesamoids. The mean duration until bone union was 2.9 months (SD ± 0.8 months). The mean duration until returning to sports was 5.3 months (SD ± 3.6 months). The VAS score improved from 72.1 (SD ± 15.2) preoperatively to 12.0 (SD ± 26.7) postoperatively. The JSSF score improved from 58.7 (SD ± 15.8) preoperatively to 95.0 (SD ± 11.0) postoperatively ($P < 0.01$, respectively). All patients except the two previously described achieved a VAS score of 0 and a JSSF score of 100 postoperatively. The remaining 2 patients with congenitally distinct sesamoids and fractures had poor outcomes. No complications were observed. **Conclusions:** Nine of the 11 patients reported complete resolution. The remaining two patients with congenitally distinct sesamoids and fractures had poor outcomes.
been reported with open sesamoidectomy; however, the complication rate is high. Nayfa et al. reported a case series of 19 patients who underwent sesamoidectomy; of these patients, 8 experienced postoperative hallux valgus. Shimozono et al. performed a systematic review of sesamoidectomy and reported a complication rate of 22.5%. Nakajima reviewed a case series of 14 patients who underwent arthroscopic sesamoidectomy; they reported that 12 of the 14 patients experienced some complications. The high occurrence of complications may be associated with the removal of the sesamoid.

Sesamoid-preserving procedures, including percutaneous screw fixation and open autologous bone grafting, may be more promising than sesamoidectomy. Regarding percutaneous screw fixation, Blundell et al. investigated a case series of 9 patients and reported that the American Orthopaedic Foot and Ankle Score improved from 46 to 80, and that no complications were observed. Regarding autologous bone grafting, Anderson and McBryde reviewed a case series of 21 patients and reported that 19 patients achieved bone union; the remaining 2 patients with persistent nonunion underwent sesamoidectomy later. They also reported that among 18 patients who answered follow-up questionnaires, 17 returned to their pre-injury level of sports and occupational activities. However, reports of these procedures are scarce; therefore, their effectiveness remains unclear.

The purpose of this study was to review the outcomes of patients with hallux sesamoid fracture nonunion who underwent arthroscopic autologous bone grafting. We hypothesized that this procedure would result in good outcomes and few complications.

**Methods**

This study was approved by the Institutional Review Board of Yashio Central General Hospital (approval number: YIHCE002-02). The medical records of patients with hallux sesamoid fracture nonunion who underwent arthroscopic autologous bone grafting from July 2017 to April 2020 after the failure of more than 6 months of conservative treatment were reviewed. Informed consent to use the medical records was acquired from the patients before surgery. The inclusion criterion for this study was 2 years or more of follow-up. The exclusion criterion was less than 2 years of follow-up.

**Surgical Technique**

Arthroscopy of the first MTP joint was performed using Nakajima’s method. A fluoroscopic monitor, C-arm, and arthroscopic monitor were placed cranially to caudally on the operated side, and a transverse bar for traction was set at the end of the table (Fig 1). The surgeon stood beside the unoperated feet. The proximal phalanx bone was drilled transversely using a 1.8-mm K-wire, and a 0.9-mm soft wire was passed through...
the hole. Then, the soft wire was circled for traction. An adjustable traction device (Kent Retractor; Takasago Medical Industry, Tokyo, Japan) was attached to the transverse bar, and the traction hook of the device was connected to a circle. The hallux was wrapped with gauze to avoid damage by the soft wire (Fig 1).

A dorsomedial portal was marked at the medial edge of the first MTP joint using an anterolateral fluoroscopic view, and a distal sesamoid portal was marked at the bottom of the MTP joint using a lateral fluoroscopic view and surgical pen (Fig 1). Traction was applied to the hallux. A 5-mm skin incision was made at the planned dorsomedial portal, and blunt dissection was performed to reach the joint. A 2.3-mm, 30-degree arthroscope (Stryker, Kalamazoo, MI) was introduced into the joint and directed to the plantar site. The infusion pump (FloSteady Stryker) was set to the autocalibration mode. An 18-G needle penetrated the planned distal sesamoid portal in the joint. When the needle was identified arthroscopically in the medial gutter, the surgeon pulled the needle out. Subsequently, the no. 11 blade was introduced into the joint in the same direction as the needle to incise the skin and joint capsule to create a proximal sesamoid portal. G, medial gutter; M, metatarsal head; N, needle; S, tibial sesamoid.

Bone Graft Harvesting

A 2-cm skin incision was created on the iliac crest, and blunt dissection was performed to reach the ilium. After the periosteum was incised and denuded, the bone graft was harvested using an osteochondral autograft transfer system (Arthrex, Naples FL). The bone shape was cylindrical, with a diameter of 6 mm and a length of 15 mm (Fig 4). The defect of the ilium was filled with bone substitute material (Ostinate;
Bone Grafting Preparation
Cancellous bone harvested from the iliac crest was fragmented as much as possible (Fig 4). The hooded bur was separated into the hood and bur, and fragments of the bone graft were crammed into the hood using a bur. After filling the bone fragments with the hood, the bur was returned to the hood, and the fragments in the hood were confirmed fluoroscopically (Fig 4). The bone fragments were filled in the hood such that the length of the fragments was approximately twice that of the diastasis.

Bone Grafting
After filling the bone fragments with the hood, the arthroscope was introduced from the distal sesamoid portal, and the hood was introduced from the proximal sesamoid portal and advanced in the diastasis until the tip of the hood reached the lateral edge of the diastasis under fluoroscopic and arthroscopic guidance (Fig 5). Bone grafting was performed by pulling out the hood while pushing the bone graft with a bur. When bone grafting was completed, the tips of the hood and bur were at the medial edge of the tibial sesamoid (Fig 5). The bone graft was confirmed arthroscopically (Fig 5). Finally, traction was released, the foot was rotated externally, and the bone graft placed in the diastasis was confirmed fluoroscopically (Fig 6). Incisions of the portals were sutured using 5-0 nylon.

Postoperative Management
Passive plantar flexion exercise of the hallux was initiated 1 day after surgery to prevent adhesion of the extension hood to the dorsomedial portal. The existence of adhesions was confirmed by active dorsiflexion. Passive dorsiflexion and active plantar flexion were not allowed until 6 weeks after surgery. Unrestricted range-of-motion exercises were initiated 6
weeks after surgery. Walking with a postoperative shoe that reduced the weight-bearing pressure of the forefoot (OrthoWedge shoe; DARCO, Huntington, WV) was started 1 day after surgery. Walking without an orthosis was started at 6 weeks after surgery. Postoperative follow-up roentgenography was performed every 2 weeks. When X-ray imaging showed the appearance of bone union after 10 weeks postoperatively, CT of a 1-mm slice was performed to confirm complete union of the bone (Fig 7). Then, sports activities were initiated as tolerated.

Data Collection and Statistical Analysis

Data regarding age, sex, body mass index, preoperative and postoperative visual analog scale (VAS) scores, preoperative and postoperative Japanese Society for Surgery of the Foot (JSSF) scores,22,23 duration until bone union, and return to sports after surgery were obtained from the medical records. Preoperative data were obtained 1 month before surgery, and postoperative data were obtained during the final follow-up. The postoperative improvements were analyzed using the Wilcoxon signed-rank test. All tests were two-tailed, and differences were considered statistically significant at P < 0.05. All statistical analyses were performed using EZR version 1.38 (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a modified version of R version 3.5.2 (The R Foundation for Statistical Computing, Vienna, Austria) designed to add statistical functions frequently used in biostatistics.17,24

Results

Eleven patients (3 women and 8 men) were enrolled. The mean age was 18.6 years (standard deviation [SD] ± 10.3; range: 13-49 years). The mean body mass index was 21.9 kg/m² (SD ± 2.5 kg/m²; range: 19.2-26.3 kg/m²). The mean follow-up duration was 3.2 years (SD ± 0.8 years; range: 2.1-4.8 years). One patient had fracture nonunion in the fibular sesamoid and a hypoplastic tibial sesamoid. Another patient had fracture nonunion in the distal part of the congenital bipartite sesamoid. The remaining patients had fracture nonunion in the normal tibial sesamoids. None of the patients had apparent episodes of trauma. The mean duration until bone union was 2.9 months (SD ± 0.8 months; range: 2-4 months). Ten patients participated in sports activities (baseball, 5; basketball, 1; cheerleading, 1; badminton, 1; street dancing, 1; karate, 1). The mean duration until return to sports was 5.3 months (SD ± 3.6 months; range: 2-15 months) (Table 1).

The VAS score improved from 72.1 (SD ± 15.2; range: 50-100) preoperatively to 12.0 (SD ± 26.7; range: 0-70) postoperatively (P < 0.01). The JSSF score improved from 58.7 (SD ±15.8; range: 42-87) preoperatively to 95.0 (SD ±11.0; range: 69-100) postoperatively (P < 0.01). Nine of the 11 patients achieved a VAS score of 0 and JSSF score of 100 postoperatively (Table 1). No complications were observed.

Two patients had poor scores (patients 1 and 10 in Table 1). Patient 1 was the only patient with an affected fibular sesamoid and hypoplastic tibial sesamoid. Bone union was obtained at 5 months...
postoperatively, but the pain was not alleviated. This patient opted for arthroscopic sesamoidectomy, which was performed 1 year postoperatively, when the VAS score was 62 and JSSF score was 69 (Table 1). At the final follow-up after 4.8 years, the VAS score was 3 and the JSSF score was 85. Patient 10 had an affected tibial sesamoid, which is a congenital bipartite sesamoid, and fracture nonunion of the distal fragment. During surgery, the congenital diastasis and fracture sites were abraded, and bone grafting was performed at both sites. The diastasis site achieved bone union within 3 months, but bone union was not achieved at the distal fracture site until the final follow-up. The next treatment plan was pending at the final follow-up because the patient had not decided.

Discussion

In this study, the subjects’ VAS scores improved from 72.1 to 12.0, and the JSSF score improved from 58.7 to 95.0. Studies of several sesamoidectomies have been previously reported. Bichara et al. reported a case series of 24 patients with VAS scores that improved from 62 to 7.13 Canales et al. reported 5 patients with VAS scores that improved from 68 to 10.14 Nakajima reported a case series of 14 patients treated with arthroscopic sesamoidectomy who had VAS scores that improved from 75 to 14 and JSSF scores that improved from 55 to 88.17 These were all small case series; therefore, it is unclear whether our autologous bone grafting outcomes were better than the previously reported sesamoidectomy outcomes.

The mean duration until returning to sports was 5.3 months (SD ± 3.6 months; range: 2-15 months). This result is consistent with those of previous studies of sesamoidectomy. Bichara et al. reported that 91% (22/24) returned to activities within a mean period of 11.6 weeks.15 Biedert and Hintermann reported five patients treated with open sesamoidectomy who returned to sports within 2.5 to 6 months.10 It is unclear which procedure resulted in an earlier return to sports because the case series study was small.

No complications were observed. Shimozono et al. performed a systematic review and reported that the complication rate of open sesamoidectomy was 22%.16 Nakajima studied 14 patients treated with arthroscopic sesamoidectomy and reported that 71% (12 of 14) of patients had no complications.
patients had complications. The low complication rate of this study may be attributable to the low invasiveness of arthroscopic surgery and preservation of the sesamoid.

The mean duration until bone union during this study was 2.9 months (SD ± 0.8 months; range: 2-4 months). Anderson and McBryde studied a case series of 18 patients treated with open autologous bone grafting and reported that the mean time until bone union was 12 weeks. The durations until bone union in our study and that of Anderson and McBryde were similar.

Among the 11 patients in our study, two patients (patients 1 and 10 in the Table 1) had poor outcomes. Patient 1 was the only patient with fibular sesamoid fracture nonunion. Moreover, the tibial sesamoid was hypoplastic. Bone union was achieved at 5 months postoperatively, but the pain persisted. This may have occurred because the fibular sesamoid continued to be highly stressed by hypoplasia of the tibial sesamoid.

Patient 10 had fracture nonunion of the distal fragment of the congenital bipartite tibial sesamoid. During surgery, bone grafting was applied to the congenital diastasis and fracture site. The proximal congenital diastasis achieved bone union, but the distal fracture site did not. A study of the blood supply for the sesamoid indicated that, in the normal sesamoid, the blood supply originates from the proximal, plantar, and distal sites; however, in the bipartite sesamoid, the blood supply originates from only the proximal and distal sites. Moreover, the vessels in the bipartite sesamoid are narrower than those in the normal sesamoid, and the vessels in the distal site are narrower than those from the proximal site. These anatomical characteristics may be associated with the results of patient 10 (the proximal diastasis achieved bone union, but the distal fracture site did not). Patients 1 and 10 had congenitally distinct sesamoids and fractures. In such cases, surgery may not be feasible.
Limitations
Our study had several limitations. First, the sample size was small. Second, only one elderly patient was enrolled in this study. Third, the follow-up period was relatively short. Finally, there was no comparison group because this study was a case series.

Conclusion
Nine of the 11 patients reported complete resolution. The remaining two patients with congenitally distinct sesamoids and fractures had poor outcomes.

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