total force at 0° and 90°. On the other hand, Norwood and Cross reported their different functions in tibial rotation [17]. The IM bundle contributed to straight anterior and anteromedial stability. These results indicate the IM is a discrete functional bundle and the triple-bundle ACL reconstruction should be one of the reasonable approaches to restore the normal knee function.

Residual anterior instability measured with the KT-1000 of 0.7 ± 1.2 mm in the triple-bundle reconstruction was almost equal to that of 0.8 ± 1.0 mm in the double-bundle ACL reconstruction [18]. As mentioned above, however, the IM bundle could be assumed to have distinct biomechanical roles different from those of the AM or the PL. Further biomechanical study or development in clinical analysis of the ACL reconstruction will clarify advantages of the triple-bundle reconstruction over the double-bundle procedure.

As gross appearance of the anatomical triple-bundle ACL graft at the second-look arthroscopy resembled that of the native one, this technique could reproduce the ACL morphologically. Although a comparison study was lacking, the anterolateral portion of the tibial attachment was appeared to filled with the more robust structure in the triple-bundle reconstruction compared with the morphology of the double-bundle graft (Fig. 7a, b). In terms of graft damages, Toritsuka et al. [25] have reported on the results of second-look arthroscopy of Rosenberg's ACL reconstruction that 34% of the grafts showed partial tear in their anterior portion, suggesting graft impingement against the intercondylar notch or the PCL. On the contrary, the anatomically placed grafts in the double-bundle reconstruction showed no damage in the anterior portion [18]. Theoretically, the IM graft in the triple-bundle technique has greater risk of impingement against the medial aspect of the lateral femoral condyle than the AM graft in the double-bundle procedure because of its alignment. In our cases, however, this type of graft damage was not seen. This suggests that the anatomically placed grafts could avoid the risk of the impingement, even if the notchplasty was not combined.

On the other hand, there were substantial damages in 10% of the PL grafts as seen in cases of the anatomical double-bundle ACL reconstruction [18]. In addition, poor synovial coverage was observed in 41% of the PL grafts around the femoral tunnel aperture. These poor results in the PL grafts might be due to greater length change of the graft during extension–flexion movement. Iwahashi et al. have compared differences in the length change among three bundles of the natural ACL using MRI-based three-dimensional virtual models. Therefore, length change of the PL graft in the current triple-bundle procedure could be assumed the largest among these three bundles [9]. Furthermore, shorter PL graft results in the shorter distance between the femoral and tibial fixations for the PL graft. These might lead to increase in force change to the graft during flexion–extension movement, to more pronounced "bungee cord" effect, and to poorer graft-to-bone tunnel healing around the femoral tunnel aperture [7, 12, 21]. Improvement in graft fixation to shorten the distance between femoral and tibial fixations might reduce this unfavorable effect to achieve better graft-tunnel healing. Another potential factor to affect the healing process could be the rehabilitation program at an early phase after surgery. In our study, patients wore a knee brace for 1 week, and further study will be required to examine whether postoperative bracing for more than 1 week has a positive effect on the healing. Although these poor results in second-look arthroscopy have not yet resulted in clinical failures at 2 years postoperatively, the cases with better synovial coverage on second-look arthroscopy have been reported to present better clinical results [11] and this attenuated area may be subject to further graft rupture in the future and to symptomatic instability.

One limitation of this study could be lacking in the other evaluation modalities such as MRI or relatively short duration of follow-up. While arthroscopic evaluation can address the grafts' surface only, MRI is the other useful way to evaluate the core portion of the grafts [16]. In addition, longitudinal assessment of the grafts can be carried out using MRI [5, 8].

The other limitations of the study included the short-term follow-up and the time delay between the arthroscopic evaluation of the graft and the clinical findings, as there was one patient who underwent the graft examination at 4.4 months. This suggests that the arthroscopic observation was performed on the grafts on the way to maturation. However, this study did bring us some information of the morphological defects in the PL grafts on clinical results at 2 years. Further follow-up with additional imaging analysis may more clearly elucidate the correlation between the current arthroscopic findings and the clinical results.

Conclusion

The morphology of the triple-bundle grafts resembled that of the natural ACL, while complete or substantial rupture was observed in 10% of the PL grafts.

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Effects of medial patellofemoral ligament reconstruction on patellar tracking

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Abstract

Purpose Medial patellofemoral ligament (MPFL) reconstruction has been performed to treat recurrent patellar dislocation. However, the effects on patellar tracking have not been well documented, particularly in patients. The purpose of this study is to compare patellar tracking pattern and chondral status at MPFL reconstruction with those at second-look arthroscopy.

Methods Between 1999 and 2008, 71 patients with recurrent patellar dislocation underwent MPFL reconstruction using a double-looped semitendinosus tendon. Of these, 25 knees in 24 patients underwent second-look arthroscopy (at 6–26 months after initial surgery), forming the subject for the present study. No other surgical procedures such as tibial tuberosity transfer, lateral release, or osteotomy were performed in any patients. To assess the patellar tracking pattern, the position of the patella on femoral groove was evaluated arthroscopically during passive knee motion through lateral suprapatellar portal.

Results Before MPFL reconstruction, the patella in all patients was shifted laterally throughout the entire range of knee motion. Immediately after MPFL reconstruction, patellar malalignment was corrected in all cases. On second-look arthroscopy, two different patellar tracking patterns were observed. In 9 knees, the patella was located on the center of the femoral groove throughout the range of motion. Meanwhile, in the remaining 16 knees, the patella was shifted laterally at knee extension and migrated to the center of femoral groove with increased knee flexion. No significant deteriorations in chondral status were seen on second-look arthroscopy.

Conclusion The present study revealed that not all improved patellar trackings after MPFL reconstruction remained intact at follow-up. Chondral status in patellofemoral joint was not aggravated by MPFL reconstruction.

Level of evidence Therapeutic studies, Level IV.

Keywords Lateral patellar dislocation · Medial patellofemoral ligament reconstruction · Second-look arthroscopy · Patellar tracking pattern · Chondral status

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Introduction

Recurrent lateral patellar dislocation, subluxation and functional instability commonly occur in patients with various combinations of predisposing factors, such as general joint laxity, abnormal Q angle, abnormal patellar morphology, femoral trochlear aplasia, and patella alta [3, 16, 30]. Movement of the patella thus varies between individuals [40]. The importance of the medial patellofemoral ligament (MPFL) as the primary soft-tissue restraint to lateral displacement of the patella has recently been corroborated by several studies [5, 7, 9, 17], and the MPFL is always injured to some extent during traumatic lateral patellar dislocations [20, 29]. Many operative techniques to reconstruct the MPFL have been described [2, 8, 23, 25, 35, 37]. Good midterm clinical results with up to 97% patient satisfaction and up to 10 years follow-up have been reported [31, 38], and MPFL reconstruction has become the first choice for treating recurrent patellar dislocation. Several reports have described the good effects of MPFL reconstruction on patellofemoral kinematics and contact pressure [4, 14, 26, 33, 34]. However, all these studies used normal cadaveric knees and examined only just after MPFL reconstruction. In many knee ligament reconstruction surgeries such as anterior cruciate ligament reconstruction, posterior cruciate ligament reconstruction, and medial collateral ligament reconstruction, biomechanical properties of implanted grafts are known to change with the effects of stress relaxation and graft remodeling [1, 42]. Although such physiological factors may also be relevant to MPFL reconstruction, it is unknown whether the restored patellar maltrackings remain intact for a long while, particularly in practical patients with a variety of predisposing factors. Furthermore, no previous reports showed clearly whether MPFL reconstruction improved or damaged the patellofemoral articular surface. The purpose of the present study was to investigate whether the patellar tracking restored by MPFL reconstruction is maintained for a long time, comparing the patellar kinematics of patients at MPFL reconstruction with that at second-look arthroscopy. To evaluate the effect of MPFL reconstruction on patellofemoral joint surfaces, chondral status at second-look arthroscopy was also compared with that at initial surgery. The hypothesis of the present study was that the patellar tracking pattern at second-look arthroscopy might differ from that immediately after MPFL reconstruction, and MPFL reconstruction did not aggravate the articular surfaces.

Materials and Methods

Between 1999 and 2008, 71 patients underwent MPFL reconstruction using a double-looped semitendinosus tendon at our hospital. All patients were diagnosed with recurrent or habitual patellar dislocation by physical examinations, with positive apprehension sign in all cases. Four patients with a history of prior knee surgery (medial tubercle transfer in two, lateral retinaculum release in two) were excluded from the present investigation. In the present study, 24 patients (25 knees; 18 women, 6 men) underwent second-look arthroscopy at median of 13.2 months postoperatively (range, 6–26 months). Median age at the time of MPFL reconstruction was 22.7 years (range, 13–43 years). Prior to MPFL reconstruction, informed consent was obtained from all patients for hardware removal with simultaneous second-look arthroscopy 1 year after the initial surgery. The surgery was performed only when the patient was willing to undergo the procedure at postoperative follow-up.

Surgical Technique

All reconstructions were performed using a modified "dual tunnel medial patellofemoral ligament reconstruction" technique reported by Toritsuka et al. [39]. First, chondral status and patellar tracking were carefully evaluated by arthroscopy. A semitendinosus autograft was then harvested through a 3-cm incision over the pes anserius. The semitendinosus tendon was exposed and released from muscle using a tendon stripper. The distal end (17 cm) of the tendon was used and was doubled over. Both free ends of the graft were connected with a No. 3 braided polyester suture using Krackow suture technique.

A small 1-cm incision was made on the lateral side of the patella, and a skin incision of approximately 5 cm in length was made from the medial patellar edge to the medial femoral epicondyle. With the patella reduced in the femoral groove, the distance between the two anatomical insertions of MPFL was measured, and the exact length of the tendon was determined. Two guidewires were transversely inserted, one from proximal one-third of the medial edge of the patella and another from the center of the patella. Patellar guidewires were overdrilled using a 4.5-mm cannulated reamer to create sockets 15 mm in depth (Fig. 1). Care was taken not to violate the chondral surface or the anterior cortex of the patella. Until 2003, patellar bone tunnels were created from the medial to the lateral

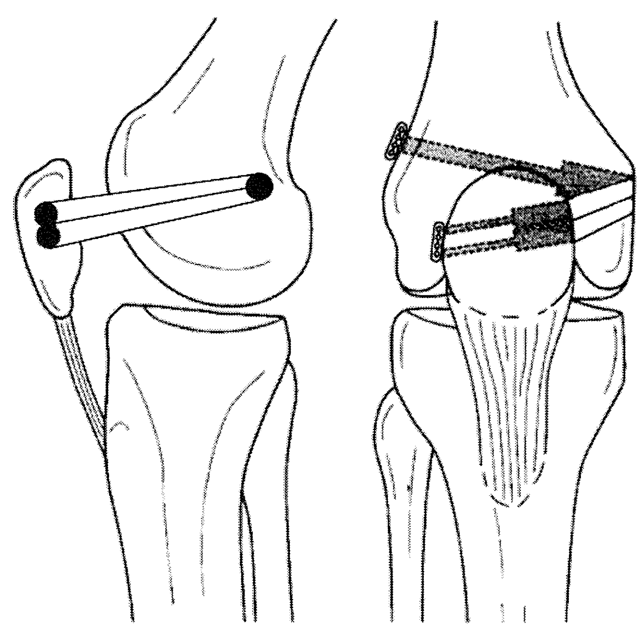

Fig. 1 Schematic view of MPFL reconstruction

side of the patella using a 4.5-mm cannulated reamer. However, the bone tunnel technique was changed to a bone socket technique in 2003 after one patient suffered patellar fracture in relation to bone tunnel procedure 2 months after MPFL reconstruction. Another guidewire was inserted from superoposterior portion of the medial femoral epicondyle toward the proximal cortex of the lateral femoral condyle. The guidewire was overdrilled with an EndoButton® drill (Smith & Nephew Endoscopy, Andover, MA), and 5- to 6-mm socket was drilled to a depth of 20 mm at the anatomical femoral insertion of the MPFL (Fig. 1).

The center of the graft was pulled into the femoral socket to a depth of pre-determined length and was fixed using an EndoButton® on the proximal cortex of the lateral femoral condyle. The two free ends of the graft were pulled into the bone sockets of the patella, and the two No. 3 braided polyester sutures connected to the graft were fixed by an EndoButton® on the lateral side of the patella at 45° of knee flexion. At this time, care was taken not to overtense the graft. After fixation of both sites, negative manual lateral dislocation of the patella was confirmed and patellar tracking was then evaluated arthroscopically (Fig. 1).

Postoperative Management

For 2 weeks after MPFL reconstruction, the knee was immobilized with a brace at 45° of knee flexion. After the brace was removed, passive- and active-assisted range of knee motion was started. Weight bearing was gradually increased to full at 4 weeks postoperatively. Running was allowed at 3 months, followed by a return to previous sporting activity at 6 months.

Evaluation

All patients were evaluated preoperatively, postoperatively, and by second-look arthroscopy. Clinical data included the incidence of recurrent subluxation and dislocation, lateral patellar hypermobility [21], lateral patellar apprehension, and Kujala score [22]. Radiographs of the knee, including a conventional anteroposterior view, lateral view, 30° skyline view, and Merchant's view, were taken at each of the three time points. The skyline view was used for measuring lateral tilt [12], and Merchant's view was used for measuring congruence angle [27] (Fig. 2). Insall-Salvati ratio at the three time points was measured on the lateral view [19]. Arthroscopically, patellar tracking was evaluated at 0° through 60° of knee flexion through a lateral suprapatellar portal. A median ridge of the patella located above the middle third of the femoral groove was defined as "centrally located", while a ridge located lateral to the middle third of femoral groove was defined as "laterally shifted". Evaluation of patellar movement was repeated three times, and it was confirmed that patellar tracking pattern was same in each time. Patellar trackings were recorded on video disc and verified by two skilled orthopedic surgeons postoperatively. Chondral status of patellofemoral joint according to the Outerbridge classification was also evaluated at initial surgery and second-look arthroscopy. The view during arthroscopic operations was kept clear by means of irrigation and tourniquet. The pressure of irrigation fluid was set to 40 mmHg, and the pressure of air tourniquet was set to 300 mmHg.

Statistical analysis

Statistical analysis was performed using the paired *t*-test, one factor analysis of variance, Mann–Whitney U test, and the Wilcoxon rank-sum test. Values of $P < 0.05$ were defined as significant.

Results

No patient reported re-dislocation of the patella in the follow-up period. All patients showed full range of motion at the time of second-look arthroscopy. One patient, who had not been allowed to return to sports activity, had

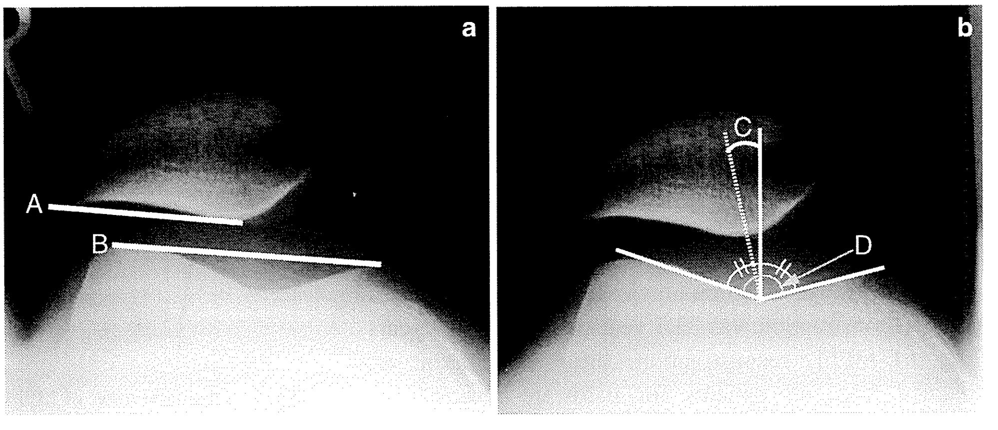

Fig. 2 Measuring methods on radiograph. **a** 30° skyline view. Lateral tilt angle was defined as an angle with *line A* to *B*. **b** Merchant view. *C* congruence angle, *D* sulcus angle

suffered patellar fracture during badminton 2 months after MPFL reconstruction and underwent open reduction and internal fixation. In terms of passive patellar hypermobility, abnormal lateral patellar movement was found in all cases preoperatively. At final follow-up, all patellae were firmly fixed on the femoral groove and no abnormal hypermobility was found in any case. While 22 knees showed clear improvements in apprehension sign, positive results were still evident in 3 cases. Median Kujala score improved from 73 (66–82) preoperatively to 95 (85–100) at second-look arthroscopy.

Radiographic Findings

Median sulcus angle was 147.7° (130–170°). Preoperatively, median lateral tilt angle, median congruence angle, and Insall-Salvati ratio were −8.0° (−44 to 20°), 20.8° (−25 to 80°), and 1.1 (0.8–1.4), respectively (Table 1). Immediately after MPFL reconstruction, these three indices had improved. However, at final follow-up, these indices had returned toward preoperative values to some extent (Table 1). Although patellar maltracking was reduced in all cases immediately after surgery, the position had shifted laterally to some extent at follow-up (Fig. 3a–c).

Patellar tracking

At arthroscopic evaluation prior to MPFL reconstruction, patellae in all cases had shifted laterally for all knee flexion angles (Fig. 4a–d). Immediately after MPFL reconstruction, all preoperative patellar maltracking was reduced, and patellae were congruent with femoral groove in 0–60° of range of motion (Fig. 4e–h). At second-look arthroscopy, tensed reconstructed grafts were recognized arthroscopically from the inside of the joint in all cases (Fig. 5). In 9 knees, the patella was always located above the center of the femoral groove within 0–60° of range of motion and thus classified as "centrally located type". In 16 knees, the patella was located in a "laterally shifted" position at knee extension, moving on the center of the femur and becoming congruent with the femoral groove as the angle of knee flexion increased. This pattern was classified as "laterally shifted type".

No demographic data affected the difference in patellar tracking between the two groups (Table 2). However, 3 patients who complained of positive apprehension sign at follow-up were classified as "laterally shifted type". Kujala scores, sulcus angles, and preoperative lateral tilt angles were not different between the two groups (Table 3). Only median preoperative congruence angle, which was 9.2° (−25 to 52°) in "centrally located type" and 26.5° (−2 to 85°) in "laterally shifted type", differed significantly according to various preoperative factors ($P = 0.03$; Table 3).

Chondral Status

At MPFL reconstruction, cartilage lesions on the patellofemoral joint were observed in 96% of patients. At second-look arthroscopy, no obvious deterioration in chondral status was seen. The patella cartilage in "centrally located type" patients showed little change, compared with that at MPFL reconstruction (Fig. 6a). In the "laterally shifted type", 2 patients displayed slight deteriorations in the patella surface and 6 patients showed improvement in lesions (4 lesions, grade 4; 2 lesions, grade 2; Fig. 6b). The femur showed no deterioration in the chondral status in "laterally shifted type" patients, while 4 of 9 patients with "centrally located type" exhibited slight deterioration in the chondral surfaces (Fig. 6c, d).

Table 1 Radiographic measurement

Median (range)	Before MPFL reconstruction	After MPFL reconstruction	Second-look arthroscopy	Significance (*P* value)
Lateral tilt angle (°)	−8.0 (−44 to 20)	5.5 (−16 to 20)	−3.8 (−48 to 18)	<0.05
Congruence angle (°)	20.8 (−25 to 80)	−11.8 (−64 to 45)	9.3 (−27 to 92)	<0.05
Insall-Salvati ratio	1.1 (0.8 to 1.4)	1.0 (0.8 to 1.3)	1.1 (0.8 to 1.4)	<0.05

One-factor ANOVA

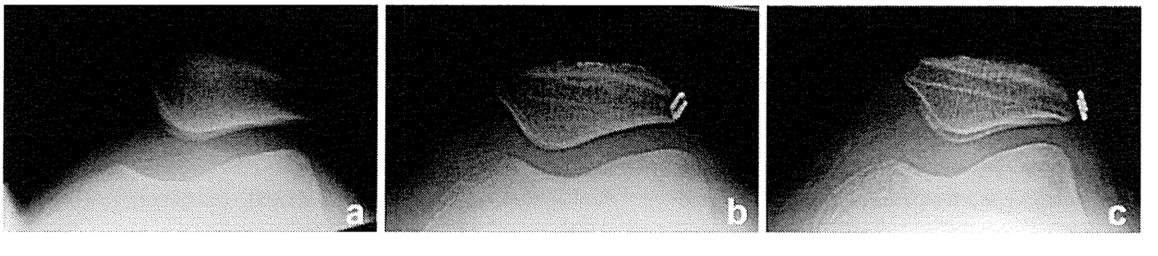

Fig. 3 Radiographs of Merchant's view at the three time points. **a** Before surgery, **b** Immediately after surgery, **c** Second-look arthroscopy

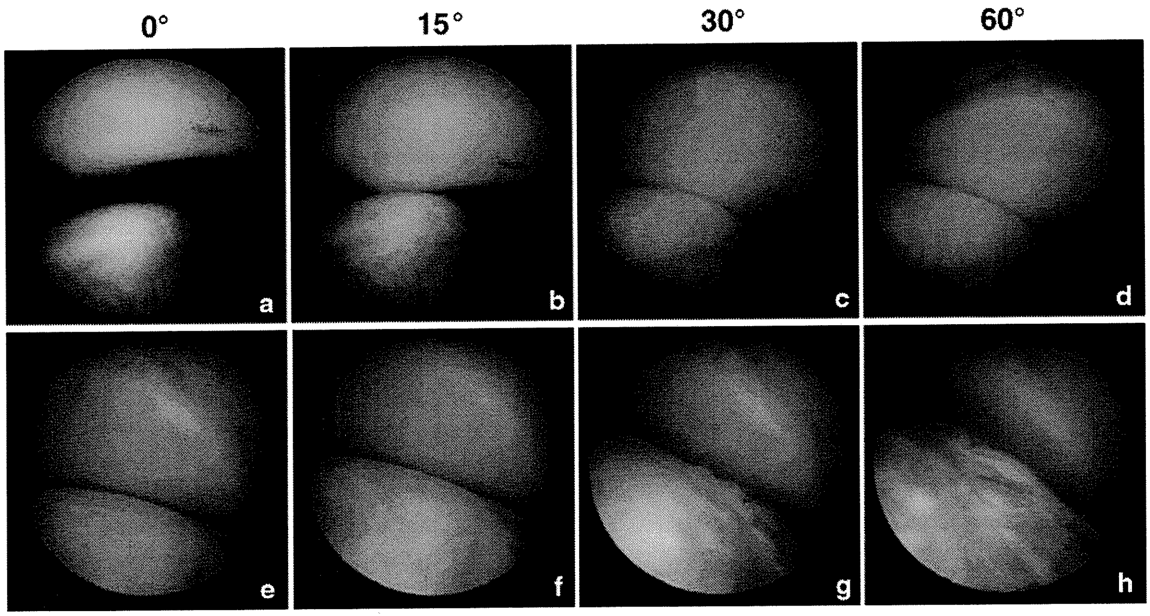

Fig. 4 Arthroscopic view of the patellofemoral joint at MPFL reconstruction. Arthroscopic view of the patellofemoral joint at 0° (**a**), 15° (**b**), 30° (**c**), 60° (**d**) before surgery and 0° (**e**), 15° (**f**), 30° (**g**), 60° (**h**) immediately after surgery

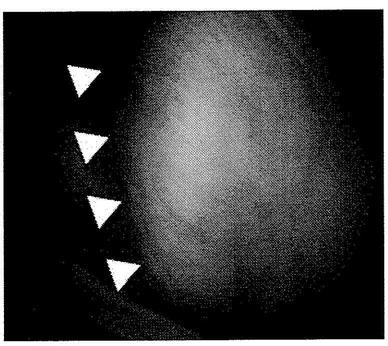

Fig. 5 Arthroscopic view of reconstructed MPFL at second-look arthroscopy. *Arrowheads* indicate a reconstructed MPFL

Discussion

The most important finding in the present study was that not all instances of reduced patellar tracking remained intact despite good clinical outcomes, even if patellar maltracking had been completely restored just after MPFL reconstruction. Arthroscopically evaluated patellar tracking patterns at follow-up were divided into two types: with 36% of patellar trackings classified as "centrally located type", and 64% classified as "laterally shifted type". All patellar tracking patterns of the three cases complaining of positive patellar apprehension were "laterally shifted type". Preoperative radiographic measurements revealed a significant difference only in the congruence angle between the two groups. No significant deteriorations in chondral status were seen on second-look arthroscopy. However, grade 1 cartilage damages that had not been recognized in initial surgery was observed in the femoral groove for 44% of the "centrally located type" patients and in the central ridge of the patella for 13% of "laterally shifted type" patients,

Although MPFL reconstruction has become the first choice for treating recurrent patellar dislocation and good midterm clinical results with up to 97% patient satisfaction and up to 10 years of follow-up have been reported [31], patellar tracking after MPFL reconstruction, particularly in

Table 2 Demographic data of "centrally located type" and "laterally shifted type"

Median (range)	Centrally located type	Laterally shifted type	Significance (*P* value)
Patient age (years old)	25.6 (15–39)	22.1 (13–43)	n.s.
Duration from injury to MPFL reconstruction (years)	10.2 (1.6–23.3)	6.7 (0.2–22.7)	n.s.
Duration from initial surgery to second-look arthroscopy (months)	10.5 (6.7–26.0)	14.2 (5.9–31.1)	n.s.
Kujala score at second-look arthroscopy	95 (85–100)	94 (81–100)	n.s.
Apprehension sign at second-look arthroscopy (−/+)*	(9/0)	(13/3)	–

Paired *t*-test

* (−/+) represents that apprehension sign is negative/positive

Table 3 Preoperative radiographic findings in "centrally located type" and "laterally shifted type"

Median (range)	Centrally located type	Laterally shifted type	Significance (*P* value)
Sulcus angle (°)	147.6 (138 to 156)	147.7 (130 to 170)	n.s.
Lateral tilt angle (°)	−0.5 (−13 to 8)	−11.7 (−44 to 20)	n.s.
Congruence angle (°)	9.2 (−25 to 52)	26.5 (−2 to 85)	0.03
Insall-Salvati ratio	1.2 (1.0 to 1.4)	1.1 (0.8 to 1.4)	n.s.

Mann–Whitney *U* test

patients, has not been described. Radiologic findings showed that all patellar maltracking was reduced immediately after MPFL reconstruction. However, tracking position had shifted somewhat laterally by second-look arthroscopy. Deie et al. reported clinical and radiologic results of MPFL reconstruction using transferred semitendinosus tendon 5 years after surgery [11]. They concluded that congruence angle, tilting angle, and lateral shift ratio were within normal ranges at 5 years postoperatively. However, detailed examination of their data showed that the three indices were improved at 6 months after reconstruction, but tended to return toward preoperative values to some extent. This fact is consistent with the present results, which found a lateral shift in the patella at follow-up. As a tensed graft was recognized from inside the joint in all cases and relatively good results were obtained in this series, the transplanted graft might undergo remodeling or stress relaxation without breaking [18], and the graft might function as a seatbelt to reinforce lateral displacement of the patella. Yamada et al. reported 3-dimensional morphological differences in the articular surface of the femoral trochlea in patients with recurrent dislocation of the patella using 3-dimensional computational models [41]. They concluded that the lateral border of articular cartilage of the trochlea in patients was located more laterally than in the control group. The two patellar tracking patterns observed in this study might have been caused by the unique patellofemoral congruency in recurrent patellar dislocation patients, as cases with subdislocation of the patella at knee extension showed significantly higher congruence angles. Furthermore, patients with patellar subluxation exhibit a tight lateral retinaculum [15]. With larger

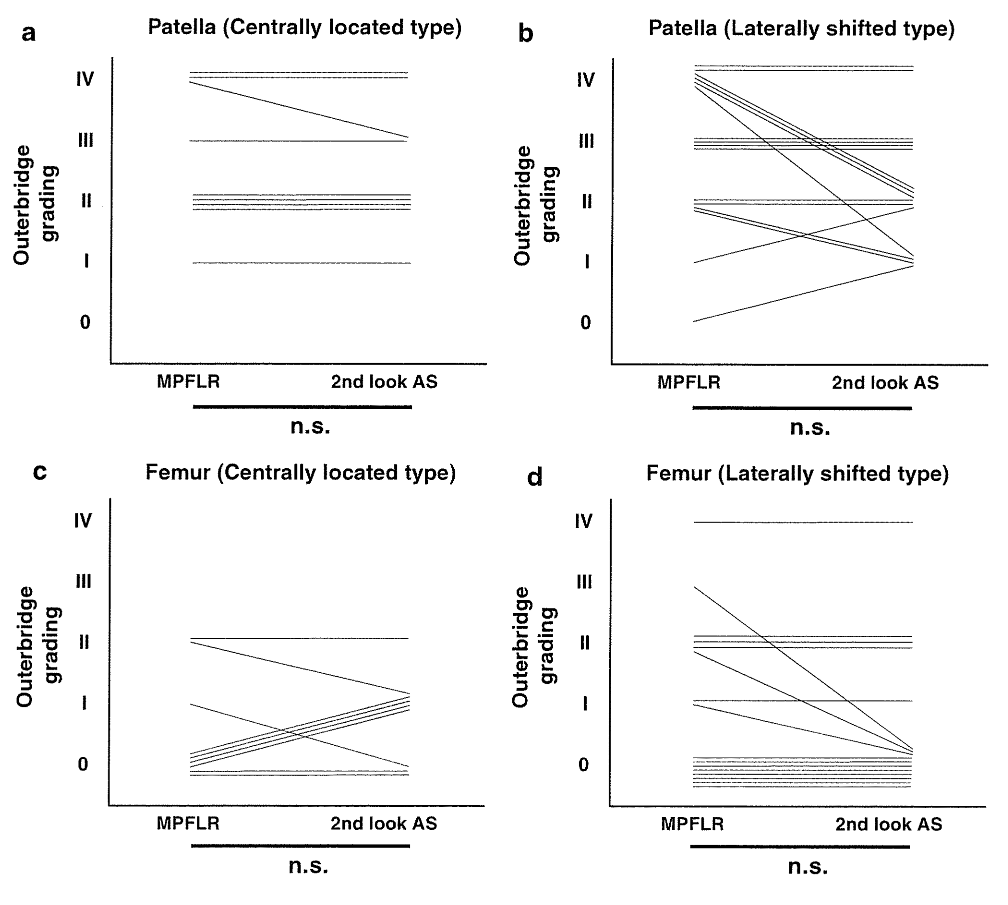

Fig. 6 Chondral status at MPFL reconstruction and at second-look arthroscopy. **a** Chondral status of the patella in "centrally located type". **b** Chondral status of the patella in "laterally shifted type". **c** Chondral status of the femur in "centrally located type". **d** Chondral status of the femur in "laterally shifted type"

congruence angle, the tighter and shorter the lateral retinaculum is considered to be. The reconstructed MPFL may be matched to the proper length by remodeling depending on individual patello-femoral congruence and tightness of the lateral retinaculum. However, all three cases with positive apprehension sign remaining at follow-up were classified into "laterally shifted type". For such cases, other surgical procedure such as lateral retinaculum release or tibial tuberosity transfer may be necessary, although further examination of this issue is needed before such recommendations can be made.

Patellar tracking of normal and abnormal subjects has been investigated using radiograph, computed tomography, magnetic resonance imaging, and arthroscopy by many authors [6, 12, 36]. Arthroscopically, quantitative evaluation of the patellar position is impossible. Brossmann et al. reported that the arthroscopic patellar tracking pattern correlated with motion-triggered cine magnetic resonance imaging [6]. By simplifying the classification of arthroscopic patellofemoral alignment, they minimized the influence of subjective impressions by operators. Arthroscopic evaluation of patellar tracking in the present study might have been subjective, but arthroscopy remains an important technique for evaluating patellofemoral problems. In the present study, although the subluxing patella was not centered on the femoral groove with increased knee flexion before surgery and patellar maltracking had been reduced immediately after surgery, arthroscopic patellar tracking patterns observed at second-look arthroscopy could be simply classified into two types, retrospectively. The influence of operator subjectivity was thus considered minimal. The pressure of irrigation fluid is another important factor affecting arthroscopic patellar tracking. Delaunay and Kapandji reported that serum inflow affected patella-trochlear centralization [13]. In the present study, to avoid differing effects of irrigation pressure on patellar tracking, the pressure was set to 40 mmHg in each case. The tracking pattern in the present study might not reflect the true pathology, but the present findings could provide useful information regarding alternations in patellar tracking after MPFL reconstruction.

Although movement of the patella varies among patients with recurrent patellar dislocation [40], the two patellar tracking patterns were observed only with reconstruction of the MPFL anatomically without any procedure for various predisposing factors. Sandmeier et al. compared patellar tracking in cadaveric knees with medial restraints intact, either sectioned or reconstructed [34]. They concluded that, with a lateral force applied to the patella, patellar tracking changed significantly with loss of the medial restraints and improved after MPFL reconstruction using a gracilis tendon. They also noted that patellar tracking was not completely restored, and the reconstructed MPFL tended to overconstrain the specimens, particularly under knee extension. Ostermeier et al. compared the effects of two different techniques of MPFL reconstruction using cadaveric knees and concluded that both reconstruction techniques created sufficient stabilization of the patella, but that patellar position was slightly overmedialized following MPFL reconstruction with a semitendinosus autograft, which could lead to overload on the medial retropatellar cartilage [32]. The present results are partially in accordance with their results, with the patella medialized and overconstrained immediately after reconstruction. However, both studies used cadaveric knees, and patellar tracking immediately after MPFL reconstruction was evaluated in vitro. Cadaveric studies do not always throw light on the true pathology of lateral patellar dislocation and MPFL reconstruction, as lateral patellar dislocation caused by various predisposing factors and physiological effects such as graft remodeling cannot be evaluated. Therefore, patellar tracking patterns in actual patients approximately 1 year after surgery were investigated.

In "centrally located type" knees, the patella was always centered in the femoral groove from 0° to 60° of knee flexion. This type of patellar tracking might differ from normal patellar tracking, as the median ridge of the patella lies lateral to the center of the trochlea in the normal knee from 0 to 30° of flexion, then moves medially to become centered in the femoral groove at between 30° and 60° of flexion [10]. In fact, 44% of the chondral status of the femoral groove in the "centrally located type" cases was deteriorated to grade 1 at second-look arthroscopy. This suggested that, in some cases, MPFL reconstruction was overtensioned immediately after surgery. Meanwhile, in the "laterally shifted type", the patella was located lateral to the center of the femoral groove and become centered with an increase in knee flexion angle. Two of 16 "laterally shifted type" patients showed deterioration at the central ridge of the patella. This fact suggests that the return of incongruence caused that excessive lateral pressure would also return. Even though the same MPFL reconstruction in all cases was performed, different patterns of patellar tracking were observed. In some cases, the reconstructed MPFL might be overtensed immediately after surgery. In other cases, the reconstructed graft might undergo graft remodeling or stress relaxation, and excessive lateral pressure might return. Long-term follow-up is needed to assess the progression of osteoarthritis. Any important factors contributing to the two types of patellar tracking could not be identified in this study. Several specific imaging protocols designed for patellofemoral disorders have been reported, including axial view with lateral rotation of the leg, measurement of patellar height, and crossing sign [12]. The crossing sign could not be investigated for systematically due to the difficulty in obtaining lateral views with perfect superposition of the femoral condyles. The Insall-Salvati ratio was measured on lateral radiographs, but no significant differences between groups were noted. A significant difference was only identified in preoperative congruence angle between groups. Proper tension and graft length applied at MPFL reconstruction may be necessary to prevent further dislocation after surgery. Conversely, re-dislocation and return of excessive lateral pressure may occur with reductions in tension. Recurrent patellar dislocation is caused by the combination of various predisposing factors, and nobody knows the exact length of MPFL in each patient. To solve the double-edged sword problems, further research is needed.

Several limitations in this study must be considered. First, not all patients who underwent MPFL reconstruction were examined in this series. Some potential for bias in patient selection may thus exist, and the 24 patients investigated in the present study might not have been representative of the entire 71 patients. However, the cohort of 25 knees that underwent MPFL reconstruction and second-look arthroscopy represents a bigger group of patients compared with previous studies, and the information provided by this investigation is meaningful. Second, one patient suffered patellar fracture related to a drill hole in this series. Until 2003, a 4.5-mm transverse bone tunnel had been created in the patella. To decrease the potential risk of patellar fracture, the bone tunnel technique has been changed to bone socket technique using a 2.4-mm Kirschner wire. This procedure still carries some risk of patellar fracture, but a stronger initial fixation is expected by both pull-out fixation and bone-tendon healing compared with suturing to the periosteum or VMO tendon [28]. Finally, the duration between initial surgery and second-look arthroscopy might have been too short to evaluate the patellar movement after MPFL reconstruction, as the mean duration tended to be shorter for "centrally located type" than for "laterally shifted type", although the difference was not significant. No correlation was evident between the interval to MPFL reconstruction and duration of follow-up and patella tilt and congruence angle (data not shown). In anterior cruciate ligament reconstruction, the implanted graft reportedly underwent graft remodeling or stress relaxation for 6 months postoperatively [24]. This finding is relevant to MPFL reconstruction, and $\geq$6 months between initial and second-look arthroscopy is sufficient to examine patellar tracking.

Conclusion

Not all improved patellar tracking seen just after MPFL reconstruction surgery remained intact at follow-up. Two patterns of patellar tracking were observed arthroscopically following MPFL reconstruction: "centrally located type" and "laterally shifted type". No obvious chondral damage in the patellofemoral joint was seen at second-look arthroscopy, but locations showing cartilage deterioration differed between types.

Conflict of interest The authors report no conflict of interest.

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Transarticular drilling for stable juvenile osteochondritis dissecans of the medial femoral condyle

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Abstract

Purpose Drilling is the most common operative treatment for stable juvenile osteochondritis dissecans (OCD) of the knee. However, prognostic factors remain unclear because of lack of precise radiographic and histopathologic investigations. The purpose of this study was to evaluate the clinical results and prognostic factor of the arthroscopic drilling for juvenile OCD lesions at the medial femoral condyle (MFC), using computed tomography (CT) images.

Methods Eighteen skeletally immature patients (boys, $n = 16$; girls, $n = 2$, mean age, 12 years) underwent arthroscopic antegrade transarticular drilling for a total of 19 OCD lesions of MFC. Functional outcomes were evaluated with the Lysholm score at follow-up (mean, 30 months). Preoperative osteochondral condition and postoperative healing were evaluated by CT images.

Results All 18 patients returned to their previous level of sports activity and showed excellent functional outcomes (mean Lysholm score, 77.2 ± 9.4 preoperative vs. 99.5 ± 1.6 postoperative). There were 10 osteochondral lesions and 9 subchondral bone defect lesions under preoperative CT examination. Postoperatively, 15 of 19 lesions healed completely at a mean of 6 months; however, the remaining four lesions (all osteochondral types) did not achieve complete radiographic healing after 2 years.

Conclusion Transarticular drilling for stable juvenile OCD produced excellent functional outcomes. However, the osteochondral type may influence radiographic outcome.

Level of evidence Case series, Level IV.

Keywords Osteochondritis dissecans (OCD) · Juvenile · Transarticular antegrade drilling · Histopathologic evaluation · Osteochondral condition · Prognostic factor · Computed tomography (CT)

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Introduction

Osteochondritis dissecans (OCD) is a lesion of the cartilage-subchondral bone complex that primarily affects children and young adults. OCD is usually subcategorized into juvenile and adult forms, depending on the status of the physis of the femoral condyle [11, 13]. Juvenile OCD lesions exhibit less instability and have better healing potential than the adult type in conservative therapy [11, 13]. After conservative treatment fails, the choice of operative procedure is largely influenced by the intraoperative determination of fragment stability.

Drilling has been performed for juvenile stable OCD lesions that do not display a cartilage breach. Satisfactory clinical results have been demonstrated in 80–90% of patients; however, the remaining 10% experience poor results (Supplemental data) [1–3, 5, 7–10, 12, 14]. Factors that predict a poor outcome are unclear, probably because precise radiographic and histopathologic data are lacking (Supplemental data), and few studies report the cause of poor outcomes from the etiologic point of view.

Previous histopathologic studies [15, 16] have revealed that symptomatic juvenile-type OCD stable lesions exhibit underlying instability in deeper layers of the articular cartilage and yet there were no or little breach in the articular cartilage surface arthroscopically. These lesions were divided into two unique histologic patterns: (1) thick homogeneous hyaline cartilage alone and (2) nearly normal, thin hyaline cartilage above a mixed layer of hyaline cartilage and subchondral trabeculae [4, 16]. In these two types, fibrous/fibrocartilage tissues were observed between the OCD lesion and bone bed, indicating delayed or non-union. More fibrous tissue was generally observed in latter type lesions than in the former type [16]. In addition, these characteristic patterns were correlated well with computed tomography (CT) images of OCD lesions [16]. These backgrounds might lead hypothesis that the difference of preoperative histopathological condition of juvenile OCD lesion may reflect on the healing potential after drilling. The purpose of this study was to evaluate the clinical results and prognostic factor of the arthroscopic drilling for juvenile OCD lesions at the medial femoral condyle (MFC), using CT images.

Materials and methods

Retrospective review was performed in 71 lesions of OCD surgically treated at our hospital between 1999 and 2009. Inclusion criteria were radiographic evidence of OCD of the MFC in patients with an open distal femoral physis. All patients experienced persistent pain, showed no radiographic improvement of OCD lesions for 6 months after conservative treatment, and had activity restrictions (e.g., no sports activity). Transarticular drilling was indicated for patients with intact articular cartilage of the lesion or cartilage softening confirmed by arthroscopic visualization and probing of the lesion, which were categorized as stage I according to the International Cartilage Repair Society (ICRS) classification of OCD lesions [6]. Patients with loose bodies, unstable lesions, or lesions with disrupted articular cartilage were excluded. A total of 19 juvenile OCD lesions treated by arthroscopic transarticular drilling were included in this study. The 18 patients included 16 boys and 2 girls, and the mean age at surgery was 12 years (range 11–14 years). Patients were followed up for more than 2 years (mean 30 months, SD 7.1 months, range 24–48 months).

Surgical technique

Arthroscopic intra-articular inspection was performed through the lateral and medial infrapatellar portals. The femoral condyle was evaluated for size and stability of chondral lesions by careful probing. Antegrade transarticular drilling was carried out with a 1.5-mm K-wire under radiographic or fluoroscopic visualization. The mean number of perforations was 21 (SD 6, range 10–35), depending on the size of OCD lesions (10 perforations/cm^2). Knee range of motion exercises was permitted immediately. After 4 weeks of no weight bearing, patients were allowed partial weight bearing. Full weight bearing started at 5 weeks and sports activities were permitted at 6 months postoperatively.

Preoperative CT evaluation

All OCD lesions were evaluated by reconstructed CT images. The lesion site and size were determined on the sagittal and coronal views that showed the largest size. OCD lesions on sagittal CT images showing the largest size were categorized into two groups according to the modified histologic classification [16]: subchondral defect type, demonstrating a complete defect of the subchondral line and subchondral trabeculae in CT images, indicating thick homogeneous hyaline cartilage alone histologically (Fig. 1a); or osteochondral type, exhibiting a normal appearance or partial defect of the subchondral line and subchondral trabeculae in CT image, indicating thick hyaline cartilage with laminar calcification/ossification histologically (Fig. 1c). In these two types, fibrous/fibrocartilage tissues were histologically observed between the OCD lesion and bone bed [16]. More fibrous tissue was generally observed in osteochondral type lesions than in the subchondral defect type [16].

Clinical outcomes

Functional and clinical outcomes were determined by comparing preoperative Lysholm scores and CT findings with those obtained postoperatively (3, 6, and 12 months postoperatively) and at final follow-up.

Radiographic healing was defined as resolution of radiolucent demarcation and complete filling of the subchondral bone on the sagittal view of reconstructed CT images (Fig. 1b). Classification of healing was performed on the CT images as follows: complete healing (until final follow-up) or nonhealing (incomplete healing at final follow-up) (Fig. 1d).

Statistical analysis

Preoperative and postoperative Lysholm scores were compared with the Wilcoxon signed-rank test. The healing status among two groups classified by CT images was compared using the Mann–Whitney *U* test. $P < 0.05$ was considered significant. Statistical analysis was performed with StatMate version 3.0 (Statmate, ATMS, Tokyo, Japan).

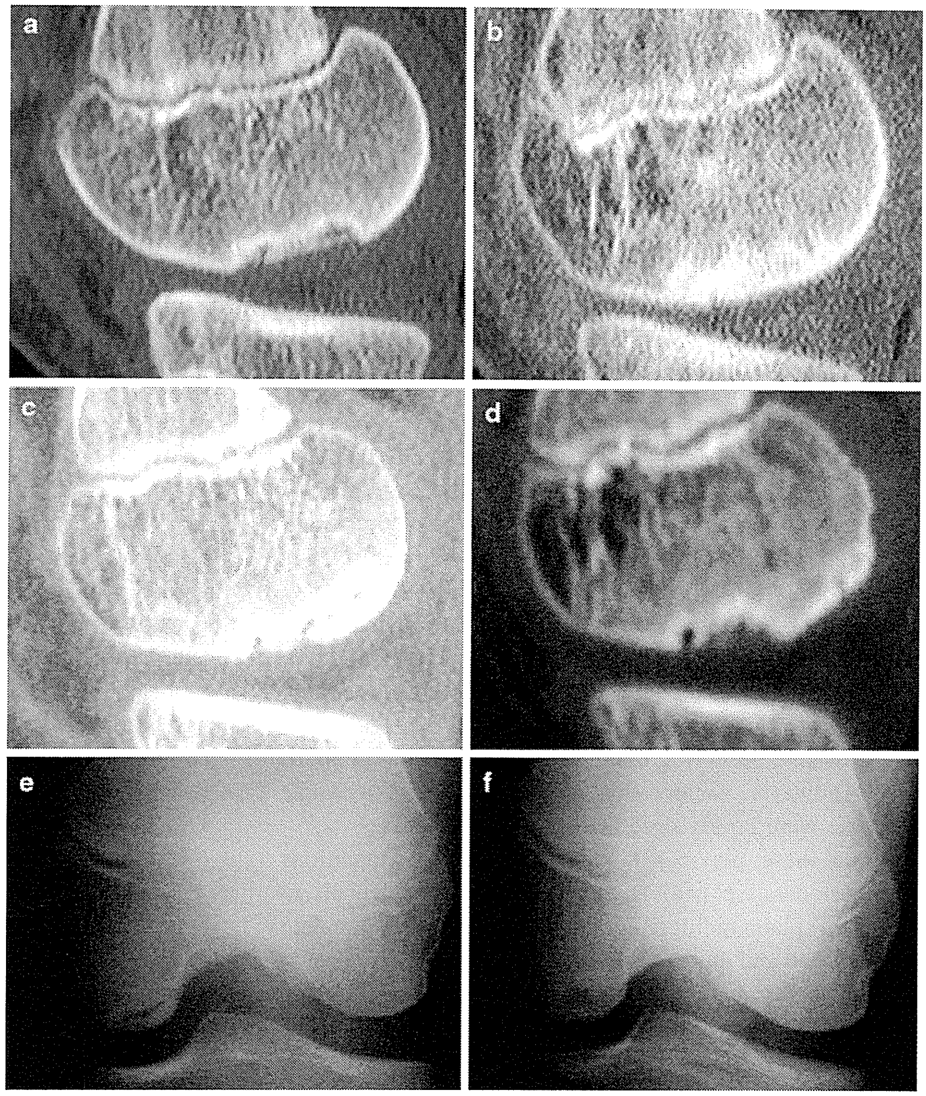

Fig. 1 Sagittal view computed tomography. **a** preoperative views and **b** postoperative view of complete healing in subchondral defect type OCD lesion. Nonhealing in osteochondral type OCD lesion: Preoperative (**c**) CT images and (**e**) plain radiography. At 2 years after drilling, **d** CT evaluation revealed partial bony union and insufficient healing, and **f** plain radiography showed union of OCD bony fragment and small lucent area in the treated area

Results

Preoperative CT classification

Mean lesion size was 2.7 cm^2 (SD 1.0, range 1.0–4.5). Nine lesions were classified as subchondral defect type, and ten lesions were classified as osteochondral type. No significant differences were detected between the two types with regard to age, height, weight, preoperative duration of symptoms, lesion size, or preoperative Lysholm score.

Clinical results

All patients had returned to their previous level of sports activity without restriction at 6 months after surgery and final follow-up. All patients except one experienced complete pain relief.

The mean Lysholm score significantly improved from 77.2 (SD 9.4, range 63–95) preoperatively to 99.5 (SD 1.6, range 95–100) postoperatively ($P < 0.001$). However, postoperative Lysholm scores did not differ significantly between the two lesion types.

Radiographic results

Reconstruction and evaluation of CT images showed that 15 OCD lesions in the healing group (9/9 subchondral defect type, 6/10 osteochondral type) achieved complete healing as assessed on both CT views at a mean of 6.7 months (SD 6.9, range 3–30). Four osteochondral type OCD lesions did not demonstrate complete healing even at final follow-up (range 2–3 years) (Fig. 1c, d); however, these four patients had complete pain relief during sports activity (nonhealing group). Osteochondral type OCD lesions were significantly less likely to heal completely ($P = 0.038$, <0.05).

Discussion

The most important finding of the present study was that excellent functional outcome was obtained in almost all of patients with OCD after drilling, although a part of patients got incomplete radiographic recovery of osteochondral structure in CT images, which is difficult to be assessed by plain radiograph. To best our knowledge, this is the first report disclosed that preoperative differences in osteochondral conditions might affect radiographic outcome after arthroscopic drilling for juvenile OCD at the MFC.

Several groups have reported successful functional and plain radiographic results after drilling of juvenile OCD lesions [1–3, 5, 7–10, 12, 14] (Supplemental data). However, several studies have reported cases of nonunion and incomplete healing [1, 2, 5, 7–9, 12] (Supplemental data). For example, Aglietti et al. [2] reported postoperative plain radiographic findings of condylar flattening in eight of 16 cases, despite observing union of the OCD lesion in all 16 cases; however, factors that appear to predict a worse outcome were poorly described etiologically.

From these previous studies, preoperative conditions and postoperative healing conditions can be difficult to detect by plain radiography. In this study, the complete regeneration and union of subchondral bone was confirmed in 15 OCD lesions on CT imaging, and four cases revealed incomplete filling of the subchondral bone, which is difficult to detect clearly by plain radiography (Fig. 1d, f). These findings indicate that CT images are a useful tool to evaluate preoperative and postoperative conditions of the subchondral bone beneath the articular surface. In the future, more precise CT evaluations of OCD lesions may reveal the course of healing and allow preoperative prediction of healing potential after drilling as well as conservative treatment.

A previous study failed to establish prognostic factors of transarticular drilling [12]. Lesion groups did not differ significantly in terms of patient height, weight, sex, lesion size, preoperative duration of symptom, or preoperative Lysholm score, similar to the previous study [12]. However, precise evaluation of CT images in the present study showed that the osteochondral type failed to heal completely in four of ten cases, whereas complete healing was observed in all nine subchondral defect type lesions. This relationship between preoperative histology and radiographic healing may be explained by the results of previous histologic studies [16]. Abundant fibrous tissue between the lesion and bone bed in the osteochondral type OCD lesion may inhibit healing by creating a channel beneath the subchondral bone. In contrast, the subchondral defect type showed little fibrous tissue. Thus, preoperative histologic differences should be taken into account while planning transarticular drilling (e.g., modification of the perforations such as several directions through same cartilage hole, and postoperative rehabilitation such as prolonged nonweight bearing).

This study has several limitations. This is a retrospective study with a small number of patients and short follow-up period, which is insufficient to address concerns about degenerative cartilage changes after transarticular drilling.

Conclusion

Transarticular drilling for patients with stable juvenile OCD of the knee is the recommended surgical procedure if the initial nonsurgical treatment fails. Reconstructed CT images of the OCD lesion are useful for precise evaluation of the preoperative osteochondral condition and postoperative healing. The characteristic osteochondral type in CT images might be a factor in the incomplete radiographic healing after arthroscopic transarticular drilling.

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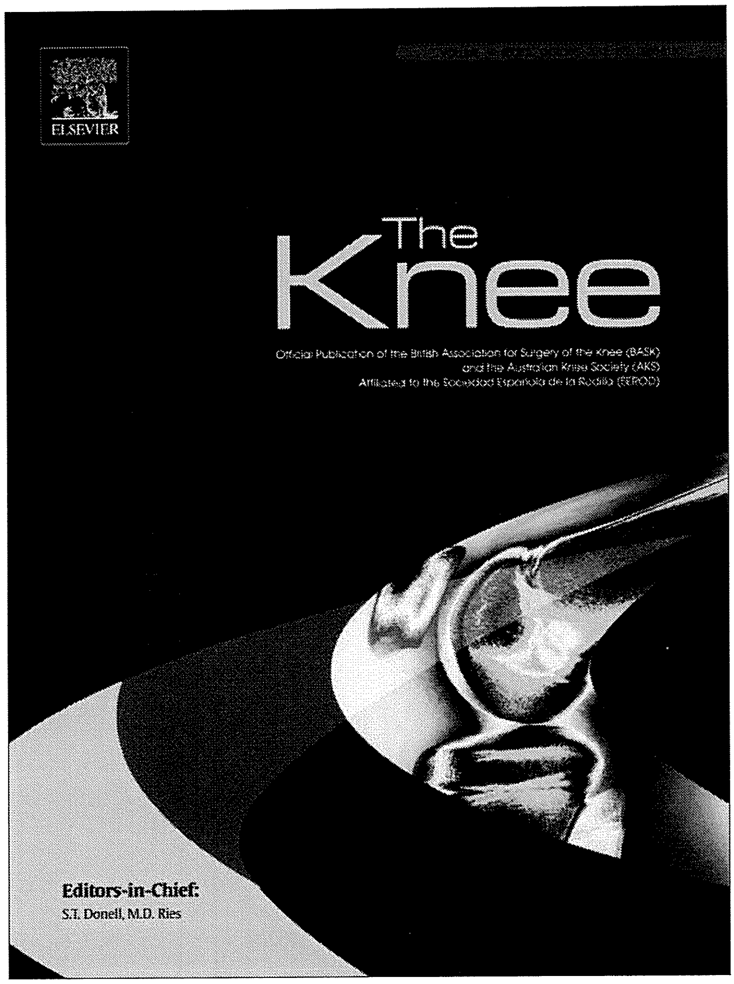
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Case report

Chondral fragment of the lateral femoral trochlea of the knee in adolescents

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ABSTRACT

Most injuries to the osteochondral region in adolescents have generally been believed to occur as osteochondral fractures. However, we report three cases of pure chondral fragments of the knee in adolescents. The patients were injured during sports activities and as a result had acute limitation of ROM of the knee joint. Only one case out of three could be diagnosed by MRI, and arthroscopic examinations were needed to make a final diagnosis in the remaining two cases. Re-fixation of the fragments was performed using bio-absorbable pins. All the patients were eventually able to return to their previous level of sports activity. Two years after the operation they experienced no symptoms and MRI showed that the re-fixed fragments were continuous to the bed without any abnormal intervening signal area, suggesting successful healing. Moreover, the arthroscopic integration between the re-fixed fragment and the surrounding articular cartilage was acceptable. Chondral fragment of the lateral femoral trochlea in active adolescents should be recognized as a clear entity that can be successfully treated by re-fixation.

1. Introduction

Most injuries to the osteochondral region in adolescents have generally been believed to occur as osteochondral fractures [4,5]; however, Nakamura et al. have reported a rare case of a purely chondral fragment from the articular cartilage of the knee which was successfully treated by fixation of the fragment accompanied by bone marrow stimulation [6]. We present here three similar cases with chondral fragment of the lateral femoral trochlea in the knee that was successfully treated by open reduction and fixation of the fragment with a minimum follow-up of two years, showing the incidence and the presumed mechanism of this injury.

2. Case reports

2.1. Case 1

A 13 year-old boy experienced sudden pain in his left knee after kicking a ball during a soccer game 5 months previously. As it spontaneously improved in time, he began to play soccer again. However, he presented to our clinic complaining of resumed knee pain during sports activities. He had limitation of extension to 45° and flexion to 90° with lateral joint line tenderness. Joint effusion, ligamentous laxity and patellar apprehension were not evaluated due to the limited ROM. Plain radiographs showed neither fractures nor free bodies. His physical status and X-ray findings are summarized in Table 1. Magnetic resonance imaging (MRI) did not show any meniscal lesions, osteochondral fragments or defects (Fig. 1). Consequently, an arthroscopic examination was performed in order to make a final diagnosis. This revealed a chondral fragment of 2 cm × 2 cm in size stuck in the popliteal recess and a matching defect of 2 cm × 1.5 cm in size on the lateral femoral trochlea covered with fibrocartilage (Fig. 2A, B). No meniscal or ligamentous lesions were observed. After capsulotomy, the fragment was removed from the popliteal recess. Macroscopically it had a lustrous, white appearance with silky-smooth palpation on both sides suggesting it was a purely chondral fragment without any attached bone (Fig. 2C, D). The fragment was trimmed to match the defect and fixed with three bio-absorbable pins (Neofix pin® Gunze, Kyoto, Japan) after curettage of the bed to the subchondral bone, accompanied by bone marrow stimulation (Fig. 2E).

The knee was immobilized in a knee brace at 30° of flexion for three weeks. After removal of the brace, the patient began passive and active ROM exercises. Partial weight-bearing was allowed at 6 weeks, followed by full weight-bearing at eight weeks. Jogging was allowed at 3 months and a return to previous sports activity at 7 months.

The patient suffered sudden knee pain and joint effusion during resumed sports activity 8 months after the operation, so second-look arthroscopy was performed. While the medial border of the re-fixed fragment remained fissured with marginal irregularity, the appearance of the lateral border was smoothly continuous to the adjacent articular

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Table 1
Patients' profile.

Case	Sex	Age	Sports	General joint laxity	Alignment[a]	Apprehension sign	FTA (deg.)[a]	Shape of patella (Wiberg's classification)	Insall-Salvati Index	Femoral sulcus angle (deg.)	Congruence angle (deg.)
1	Male	13	Soccer	–	Varus	ND[b]	179	II	1.08	131	−16
2	Male	12	Track	–	Varus	Negative	178	I	0.97	133	−7
3	Male	13	Soccer	–	Varus	Negative	177	I	1.00	134	−8

[a] Evaluated just after the operation due to preoperative limitation of ROM.
[b] Not determined (ND) due to limitation of ROM.

cartilage of the femoral trochlea, suggesting that integration of the matrix was arthroscopically sufficient only on this side (Fig. 3). The re-fixed fragment was stable when probed and one of the bio-absorbable pins was protruding. Since the joint effusion was considered to be caused by this pin protrusion, all the pins were punched into the femur because it was impossible to remove them without damage to the surrounding articular cartilage. The patient was able to return completely to the previous level of sports activity without any symptoms 2 years after the initial operation. MRI showed that the re-fixed fragment was continuous to the bed without any abnormal intervening signal area, suggesting successful healing (Fig. 4).

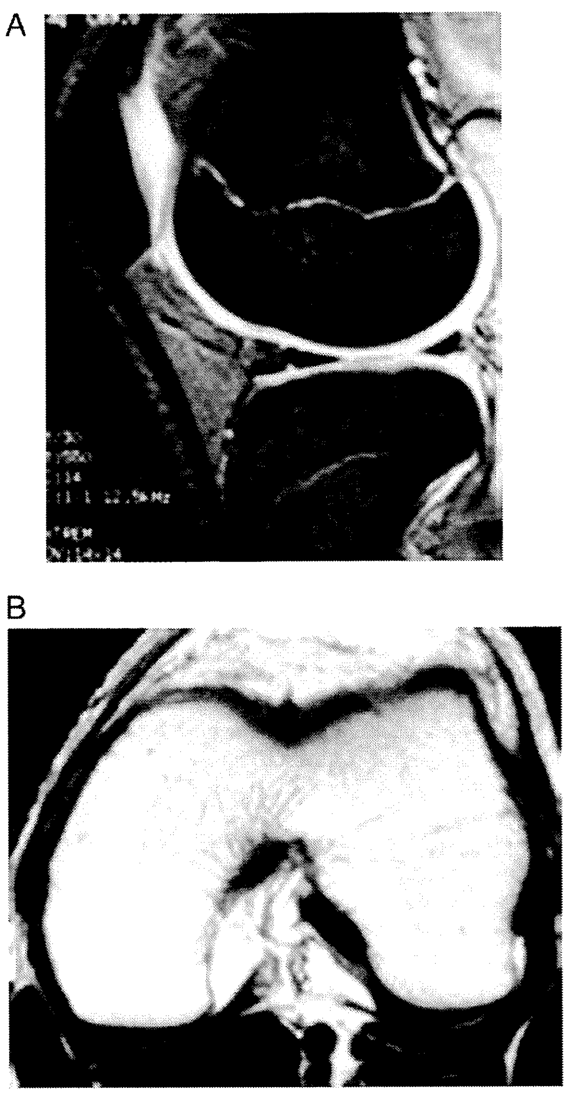

Fig. 1. Preoperative sagittal T2* (A) and axial T2-weighted MRI (B) of the injured knee of patient 1, showing no abnormality.

2.2. Case 2

A 12 year-old boy felt a pop in his left knee when he tried to speed up while running. When he presented at our clinic just after the injury, extension was reduced to 5° and flexion to 90°, accompanied by lateral joint line tenderness and joint effusion. Plain radiographs did not show any abnormality (Table 1). MRI revealed a fragment within the joint and a cartilage defect on the lateral femoral trochlea. Surgery was performed two days after the injury. We found a lustrous white fragment of 3 cm × 3.5 cm in size and a matching defect on the lateral femoral trochlea. The matching defect was covered with white fibrous tissue, which was easily peeled off by gentle probing, exposing the subchondral bone. Fixation and postoperative rehabilitation were performed in the same way as described for case 1. Three months postoperatively, second-look arthroscopy was performed. While the medial border of the re-fixed fragment remained fissured with marginal irregularity, the appearance of the lateral border was smoothly continuous to the adjacent articular cartilage, suggesting that integration of the matrix was arthroscopically sufficient only on this side, just as in case 1. Two bio-absorbable pins out of the three were removed due to protrusion from the articular surface and the remaining one was punched into the bone. Two years after the second-look arthroscopy, MRI showed that the re-fixed fragment was continuous to the bed without any abnormal intervening signal area, suggesting successful healing. The patient was able to return to the previous level of sports activity without any symptoms.

2.3. Case 3

A 13 year-old boy was kicked on the antero-medial side of his right knee during a soccer game, causing it to twist. He presented at our clinic 2 months after the injury complaining of persistent swelling of the knee. Physical examination revealed joint effusion and lateral joint line tenderness accompanied by limitation of knee flexion to 90°. Neither ligamentous laxity nor patellar instability was detected. Plain radiographs showed neither fractures nor free bodies (Table 1). Preoperatively, we examined the MRI scans that had been obtained at the previous hospital to which the patient had gone immediately after the injury. In the MRI scans, we observed increased signal intensity in the lateral femoral condyle without any meniscal lesions, osteochondral fragments or defects, while a radiologist retrospectively pointed out a low signal intensity band, although it was unclear, in the suprapatellar pouch, suggesting chondral fragment. Arthroscopic examination was therefore performed to make a final diagnosis. This revealed a chondral defect on the lateral femoral trochlea and a free cartilaginous fragment of 3 cm × 2.5 cm in size. No meniscal or ligamentous lesions were observed. The macroscopic appearance of the fragment and the matching defect on the lateral femoral trochlea was similar to case 2. The same operation and post-op rehabilitation were performed as for the above-mentioned two cases. Eighteen months postoperatively, plain radiographs showed proliferation of the subchondral bone of the lateral femoral trochlea and MRI revealed that the fragment was continuous to the bed without any abnormal intervening signal area, suggesting successful healing. Two years after surgery, the

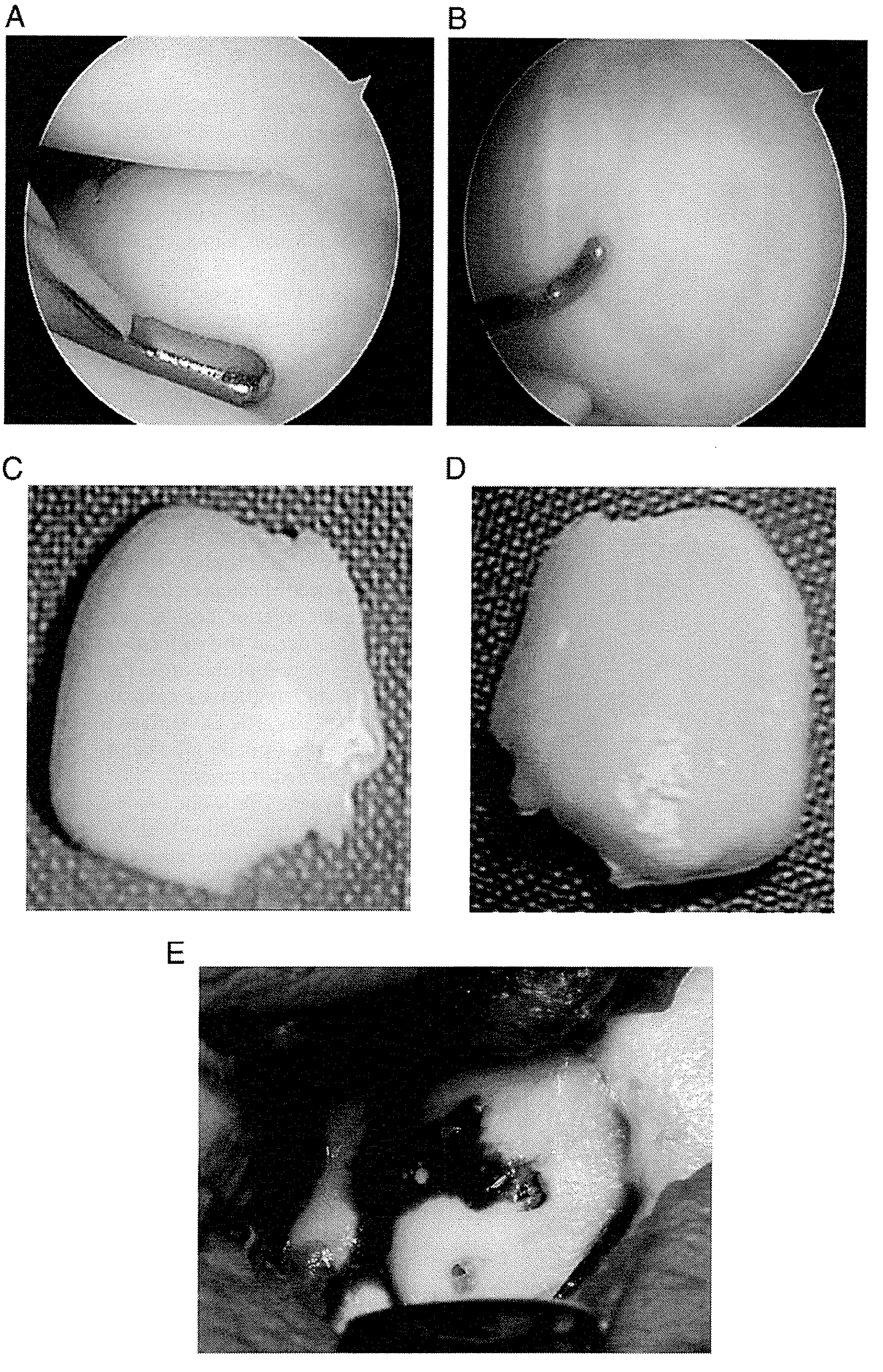

Fig. 2. Chondral fragment in Case 1. A) Arthroscopic view of the detached chondral fragment. B) The matching defect on the lateral femoral trochlea. C) Macroscopic front view of the chondral fragment. D) Macroscopic back view of the chondral fragment. E) Macroscopic view of the re-fixed chondral fragment.

patient was able to return to the previous level of sports activity without any symptoms. Second-look arthroscopy was not performed because the patient did not provide consent.

3. Discussion

We present here three cases of a purely chondral fragment from articular cartilage of the lateral femoral trochlea of the knee joint, all of which were successfully treated by surgical fixation, as previously reported as a rare injury by Nakamura et al. [6].

Incidence of this injury was just three out of 6000 patients (0.05%) presenting at the outpatient clinic of the Department of Orthopaedic Sports Medicine of the two hospitals between January 2000 and December 2009.

Regarding the mechanism of this injury, Nakamura et al. speculated, in their report [6], that a high velocity and low energy shearing force generated by a sudden twisting motion could have led to separation of the chondral layer. While shearing forces applied to the articular cartilage have been believed to cause osteochondral fractures in adolescents due to structural weakness of the osteochondral region [3], previous experimental studies indicated that the osteochondral junction was biomechanically vulnerable to shearing forces regardless of skeletal maturity, showing separation of the articular cartilage from the well-developed calcified cartilage layer [1,8]. This suggests