Clinical and Radiographic Outcomes After Fixation of Chondral Fragments of the Knee in 6 Adolescents Using Autologous Bone Pegs

Takahiro Ogura,*† MD, Hiroki Sakai,† MD, Shigehiro Asai,† MD, Hideaki Fukuda,† MD, Tatsuya Takahashi,† MD, Izumi Kanisawa,† MD, Ichiro Yamaura,† MD, Akihiro Tsuchiya,† MD, Michael Forney,‡ MD, Carl S. Winalski,‡ MD, and Kenji Takahashi,† MD

Investigation performed at the Sports Medicine and Joint Center, Funabashi Orthopaedic Hospital, Funabashi, Chiba, Japan

Background: Little is known regarding the optimal treatment for displaced, purely chondral fragments in the knee.

Purpose: To report the clinical and radiographic outcomes of chondral fragment fixation in adolescents through use of autologous bone pegs.

Study Design: Case series; Level of evidence, 4.

Methods: This retrospective, single-center study evaluated 6 patients (mean age, 12.9 years) who underwent fixation of chondral fragments (no visualized bone attached) using autologous bone pegs (mean postoperative follow-up, 5.2 years; range, 1.4-10.9 years). The causes were trauma (n = 5) and osteochondritis dissecans (n = 1). Lesions were located in the trochlear groove (lateral, n = 3; medial, n = 2) or posterior part of the lateral femoral condyle (n = 1). The mean lesion size was 3.8 cm^2 (range, 0.8-9.0 cm^2). Patients were evaluated via physical examination and magnetic resonance imaging (MRI) using magnetic resonance observation of cartilage repair tissue scores.

Results: In total, 5 patients successfully returned to sports without restrictions at a mean of 7 months (range, 6-8 months) postoperatively. At the latest follow-up, these 5 patients had full range of motion and no joint effusion. The mean magnetic resonance observation of cartilage repair tissue score was 85 (range, 70-95) at a mean duration of 3 years (range, 1-5 years). One patient experienced failure at 1.3 years postoperatively after a traumatic injury and subsequently underwent removal of the fixed fragment and a drilling procedure.

Conclusion: In most adolescents, fixation of chondral fragments with no visualized bony portion using autologous bone pegs provided a satisfactory success rate and good healing of cartilage tissue confirmed on MRI scans.

Keywords: cartilage; chondral fragment; chondral fracture; fixation; bone peg

Cartilage injury of the knee joint is difficult to manage because its ability to heal spontaneously is poor. In adolescent patients, cartilage injuries are commonly due to trauma and osteochondritis dissecans. Recommended surgical treatment options for cartilage lesions include repair with fixation of chondral fragments,[2,4,10,12,19,20,34] debridement,[9] bone marrow stimulation procedures,[33] autograft or allograft osteochondral transplant,[7,8] and autologous chondrocyte implantation.[1,21,22] A rare cartilage injury in adolescents is the delamination of cartilage, which is possibly due to weakness against the shear stress at the junction of the subchondral bone and cartilage.[5] When the free body is an osteochondral fragment with an adequate bony portion, it may be replaced and fixed into its original position to restore the native articular contour because adequate bone-to-bone healing is expected.[13] However, the optimal treatment for a purely cartilaginous free body with no bony

*Address correspondence to Takahiro Ogura, MD, Sports Medicine and Joint Center, Funabashi Orthopaedic Hospital, 1-833 Hazama, Funabashi, Chiba 274-0822, Japan (email: togura@fff.or.jp).

†Sports Medicine and Joint Center, Funabashi Orthopaedic Hospital, Funabashi, Chiba, Japan.

‡Imaging Institute, Cleveland Clinic, Cleveland, Ohio, USA.

Final revision submitted April 22, 2020; accepted June 1, 2020.

One or more of the authors has declared the following potential conflict of interest or source of funding: C.S.W. has received consulting fees and teaching fees from Aastrom Biosciences (contested by the author). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from Funabashi Orthopaedic Hospital (IRB No. 2019011).

The Orthopaedic Journal of Sports Medicine, 8(11), 2325967120963050
DOI: 10.1177/2325967120963050

TABLE 1
Patient and Lesion Characteristics (N = 6)[a]

Patient	Age, y; Sex	BMI, kg/m^2	Cause/Sport	Time to Surgery, mo	Location of Injury	Insall-Salvati Index, deg	Femoral Sulcus Angle, deg	Chondral Lesion Area, cm^2	Bone Pegs	
									No.	Diameter/ Length, mm
1	12; male	16.5	Trauma/basketball	4.9	Lateral trochlea	1.3	138	6	4	2.5/15
2	16; male	17.8	Osteochondritis dissecans / basketball	1.1	Posterior lateral femoral condyle	—	—	0.8	2	2.7/15
3	14; male	18.0	Trauma/soccer	2.8	Lateral trochlea	1.2	136	3	5	2.5/18
4	11; female	15.3	Trauma/basketball	0.5	Medial trochlea	1.4	128	0.8	2	2.0/15
5	11; male	17.8	Trauma/basketball	0.6	Lateral trochlea	1.1	134	9	4	2.1/12
6	11; female	15.1	Trauma/basketball	0.4	Medial trochlea	1.3	133	3	3	3/17

[a]All patients had open physes. BMI, body mass index. Dash indicates not applicable.

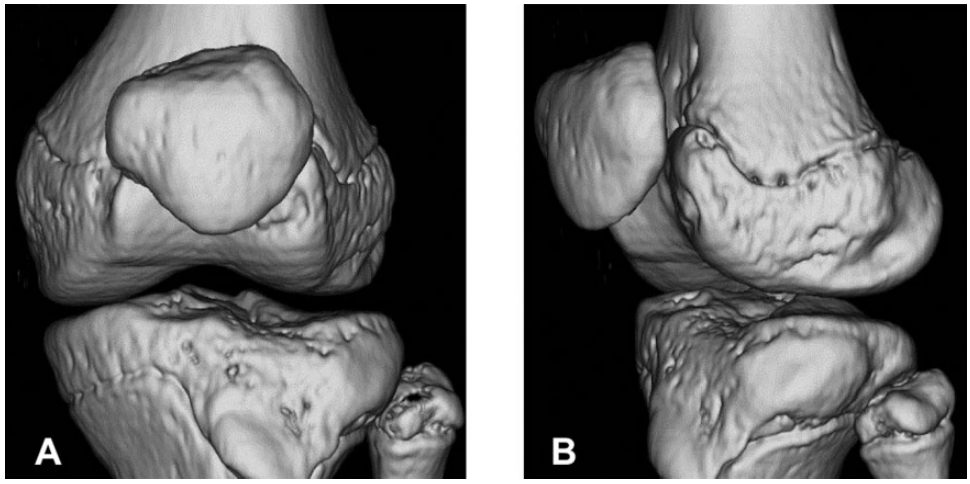

Figure 1. Preoperative reconstructed computed tomography (CT) scans (representative patient 3). (A) Front and (B) anterior oblique plane CT views show no bony fragment in the knee joint.

portion attached has not been established because of concern that the cartilage fragment will not bond to the bone. For young, active patients, restoring the joint is mandatory given that previous studies have shown that removal of osteochondral fragments results in progression to osteoarthritis in the long term.[11,18,28]

Although several studies have shown good short-term clinical outcomes after fixation of chondral fragments using metal screws or bioabsorbable screws,[2,4,10,12,19,20,34] the best fixation methods are unknown. Because of the possible advantage of biological healing enhanced by autologous tissue, we have used autologous bone pegs to fix chondral fragments and restore native joint congruity. The purpose of our study was to report clinical and radiographic outcomes of fixation of chondral fragments in adolescents through use of autologous bone pegs. We hypothesized that this procedure would provide satisfactory clinical outcomes and good healing of cartilage tissue.

METHODS

Patient Cohort

This retrospective case series was approved by our institutional review board, and assent from patients and consent from parent or guardian was obtained. Between January 2009 and October 2011, 6 patients aged <18 years were treated using open reduction and internal fixation for chondral detached fragments through use of autologous bone pegs. All 6 patients (6 knees) were included in the analysis. The patients were 2 girls and 4 boys with a mean ± SD age at surgery of 12.9 ± 1.9 years (range, 11.4-16.1 years), and the mean follow-up duration was 5.2 years (range, 1.4-10.9 years). The mean chondral lesion size was 3.8 ± 3.2 cm^2 (range, 0.8-9 cm^2). Causes included traumatic injury (n = 5) and osteochondritis dissecans (n = 1). The chondral lesions were located in the lateral trochlear groove (n = 3), medial trochlear groove (n = 2), and posterior part of the lateral femoral condyle

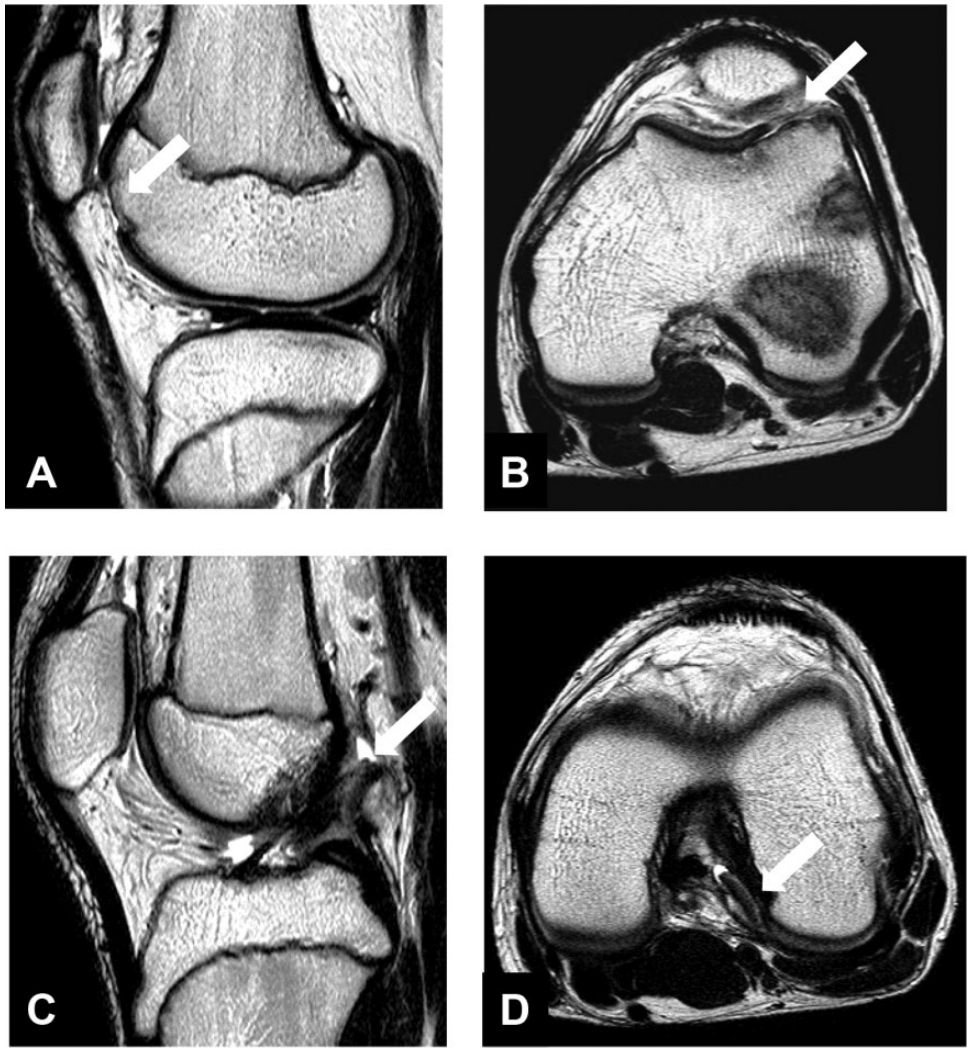

Figure 2. Preoperative magnetic resonance imaging (MRI) findings (representative patient 3). (A) Sagittal and (B) axial plane MRI scans show a cartilage defect in the lateral femoral condyle (marked by arrow). (C) Sagittal and (D) axial MRI scans show the displaced chondral fragment (marked by arrow) lying posterior to the anterior cruciate ligament.

(n = 1). The mean duration of symptoms was 1.7 ± 1.8 months (range, 0.4-4.9 months) (Table 1). In total, 5 patients were injured while playing basketball and 1 while playing soccer. No patients underwent concomitant surgical procedures during the index surgery, and no patients had previous surgery on the index knee. Among the 4 patients who had chondral injuries in the trochlear groove, no patient had patellar instability and all had normal values for the Insall-Salvati index and femoral sulcus angle.

Patient Evaluation

Preoperatively, patients were evaluated via physical examination, radiography, computed tomography (CT) (Figure 1), and magnetic resonance imaging (MRI) (Figure 2). Radiographs were taken to identify whether the distal femoral physis was open or closed at the time of the index surgery. For the purpose of this study, chondral fragments were defined as fragments that could not be seen on radiographs and CT images. Moreover, no bony portion attached to the chondral fragments was confirmed intraoperatively.

Surgical Technique

An arthroscopic examination was performed, and chondral fragments were gently removed (Figure 3). Autologous bone was harvested from the anterior tibia below the level of the tibial tuberosity to avoid the tibial growth plate, and bone pegs were made by dividing the harvested cortical bone using osteotomes (Figure 4). Depending on the size of the chondral fragments, bone pegs were adjusted to a mean diameter of 2.4 mm (range, 2-3 mm) and mean length of 15.3 mm (range, 12-18 mm). We debrided the damaged femoral articular surface of the lesions and then removed

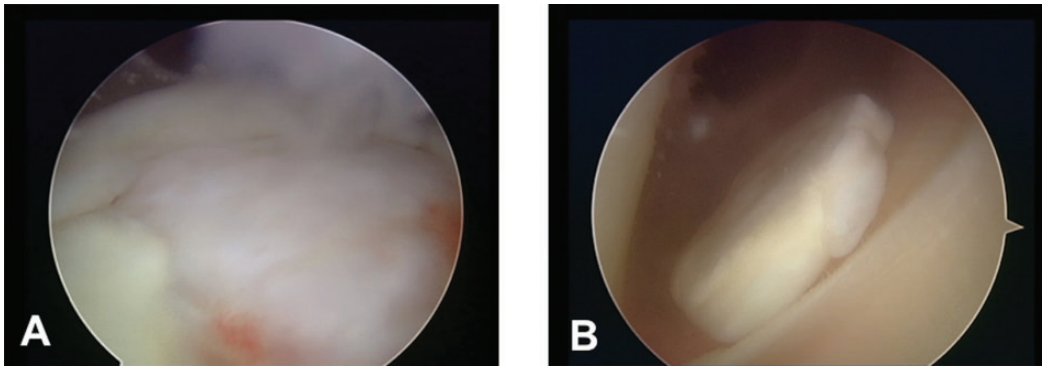

Figure 3. Preoperative arthroscopic findings (representative patient 3). (A) Cartilage defect with fibrous tissue over the subchondral bone. (B) Chondral fragment.

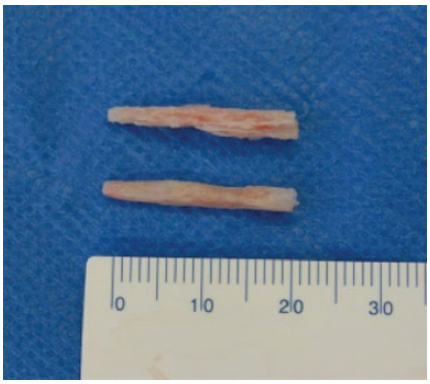

Figure 4. Bone pegs harvested from the anterior border of the ipsilateral tibia.

the fibrous tissue and calcified cartilage while trying not to damage the subchondral bone. After arranging hole sites to be placed, we drilled each hole to the same depth as the prepared bone pegs using a 1.9 or 2.4 mm–diameter drill, inserted the bone pegs, and tapped the bone pegs with a mallet for fixation (Figure 5). We did not countersink the pegs; however, we did not allow protrusion of the bone pegs from the joint surface. Caution was taken not to cross the distal femoral physis if it was still open (Figure 6). Stable fixation was confirmed by probing the area, and the joint was closed in layers.

Postoperative Course

Knees were immobilized immediately after surgery. Patients were allowed to start range of motion exercises between 0° and 60° a few days after surgery, with a gradual increase to full range of motion by 4 to 6 weeks. Patients with trochlear lesions were not allowed to bear weight for 1 to 2 weeks. Then, activity progressed to full weightbearing over the next 4 to 6 weeks. For the patient with a femoral condylar lesion, no weightbearing was allowed for 6 weeks. Afterward, there was gradual progression to full weightbearing by 12 weeks. Patients were permitted to return to most activities of daily living after approximately 3 months.

MRI Evaluation

All MRI scans were performed on a 1.5-T system (Intera 1.5 T; Philips) with an extremity coil, using a 14- to 16-cm field of view and a slice thickness of 3.5 mm. The repair sites were evaluated using the magnetic resonance observation of cartilage repair tissue (MOCART) score, in which 9 variables were used to describe the features of the repair tissue compared with those of the adjacent native cartilage.[14,15] All MRI scans were evaluated via the MOCART scoring system by 2 musculoskeletal radiologists with 8 years (M.F.) and 23 years (C.S.W.) of experience, respectively, in assessing images of cartilage repairs; the radiologists were blinded to the patient characteristics and clinical outcomes. Each radiologist read the cases separately, and differences in assessments were resolved by consensus.

Clinical Outcome Evaluation

Patients were evaluated via physical examination for characteristics including the presence of joint effusion, joint line tenderness, and limitation in range of motion. The postoperative Lysholm score and Knee injury and Osteoarthritis Outcome Score (KOOS) are reported if they were recorded.

Statistical Analysis

No sample size calculation was performed before conducting this study because this is a rare injury and all patients who met the inclusion criteria were included. The Lysholm score and KOOS subscale scores were calculated for each patient who was available to answer the questionnaires. Means and SDs were calculated for the MOCART scores.

RESULTS

Clinical Outcomes

In total, 5 of the 6 patients (83%) were successfully treated and returned to the same sports activities without restrictions at a mean of 7 ± 0.8 months (range, 6-8 months) postoperatively. At the final follow-up, none of these patients

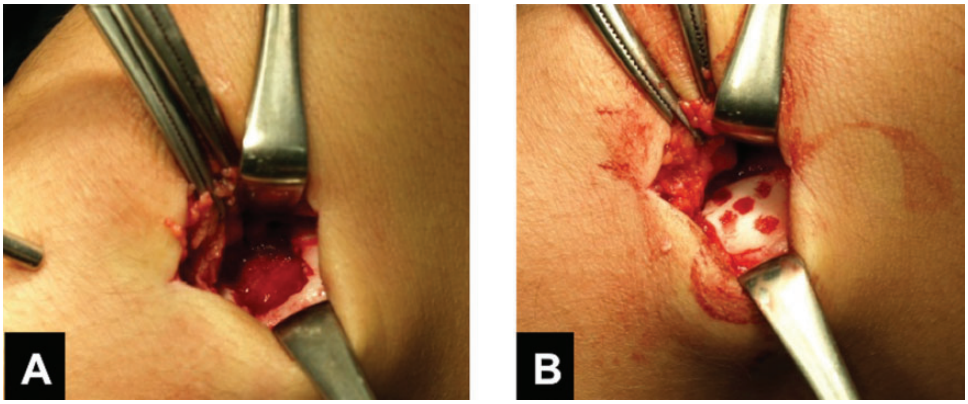

Figure 5. Chondral fragment fixation (representative patient 3). (A) The cartilage defect was debrided, and (B) the chondral fragment was fixed using impaction of the bone pegs.

Figure 6. Magnetic resonance imaging (MRI) results 3 months postoperatively (representative patient 3). Sagittal plane MRI scan shows no violation of the distal femoral physes by the bone pegs (arrow).

had joint effusion or knee tenderness, and all patients had full range of motion. The postoperative Lysholm score and KOOS from 4 patients (patients 1, 3, 4, and 6) were available at a mean of 5.9 years (Table 2) and showed excellent results, with nearly full scores for both.

We found that 1 patient (patient 5) experienced failure at 1.3 years postoperatively during an accidental fall from standing height. The patient underwent removal of the unhealed chondral fragment and a drilling procedure. The patient subsequently returned to sports activity without any limitations.

MRI Outcomes

In the 5 successfully treated patients with healed chondral fragments, postoperative MRI scans at a mean of 3 years (range, 1-5 years) postoperatively were available for evaluation (Figure 7). The mean MOCART score was 85 ± 10 (range, 70-95) (Table 3). All repair cartilage showed normal signal intensity with a complete cartilage-repair interface. In total, 4 patients had a homogeneous structure with an intact cartilage, 3 patients showed complete defect filling, and 2 patients had minor underfilling; there were no deep cartilage abnormalities. The underlying bone showed abnormalities in all patients with a subchondral lamina that was not intact. We noted that 4 of the 5 patients had subchondral bone abnormalities, including cyst and central osteophyte in 1 patient, sclerosis in 2 patients, and both sclerosis and an edema-like marrow signal in 1 patient. No patient had adhesions or effusions. No fluid lines were seen between the fixed chondral fragment and the underlying bone in these 5 patients.

In the patient who experienced failure, the lesion was located in the lateral trochlear groove (Figure 8A). After successful fixation using bone pegs, cystic lesions in the underlying subchondral bone were seen at 3 months postoperatively, which gradually increased in size and number (Figure 8, B and C). At 1 year, the fixed fragment appeared unstable with a high signal line on the T2-weighted image between the fixed fragment and underling subchondral bone (Figure 8D). At 1.3 years, the fixed chondral fragment became completely detached after an accidental traumatic injury (Figure 8E). The patient underwent removal of the unhealed chondral fragment followed by a drilling procedure. At 3 years postoperatively, the defect was covered with fibrous tissue after removal, and drilling was performed as a salvage procedure (Figure 8F).

DISCUSSION

Our retrospective case study of 6 adolescents who underwent fixation of purely chondral fragments using autologous bone pegs showed a success rate of 83% over a 5.2-year follow-up. MRI scans showed good structural results of the healed cartilage tissue with a mean MOCART score of 85 in the successfully treated patients. To our knowledge, this is the first study to report outcomes after fixation of chondral-

TABLE 2
Postoperative Patient-Reported Outcome Measures[a]

Patient	Time to evaluation, y	Lysholm Score	KOOS Subscale Scores				
			Pain	Symptoms	ADL	Sports/Recreation	QOL
1	10.9	100	100	100	100	100	100
3	1.8	95	100	100	100	100	94
4	9.2	100	100	100	100	100	100
6	1.9	100	100	100	100	100	100

[a]ADL, Activities of Daily Living; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, Quality of Life.

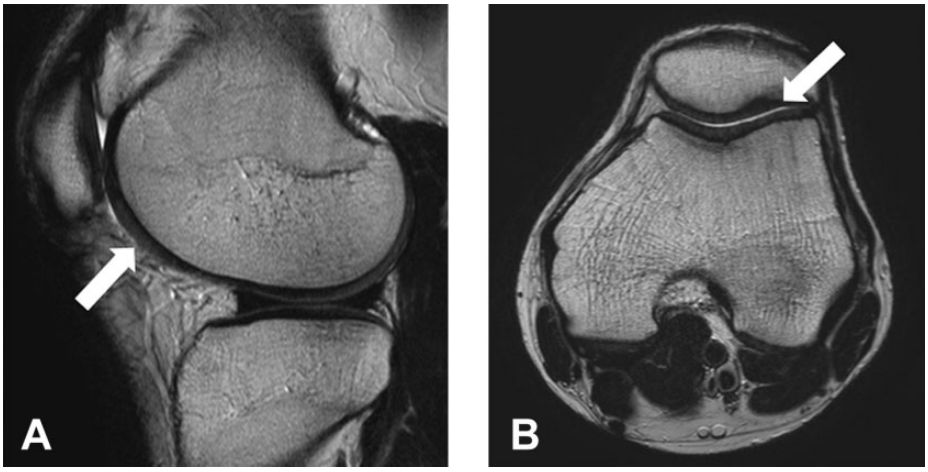

Figure 7. Magnetic resonance imaging (MRI) results at 5 years postoperatively (representative patient 3). (A) Sagittal and (B) axial plane MRI scans show good healing of the fixed chondral fragment into the lateral femoral condyle (marked by arrow). The MOCART score was 95. MOCART, magnetic resonance observation of cartilage repair tissue.

only fragments using autologous bone pegs in adolescents with objective MRI evaluations.

Several studies of pediatric and adolescent patients after fixation of chondral fragment using bioabsorbable screws have shown promising clinical outcomes over a short-term period,[2,4,10,12,19,20,34] with most of these studies being case reports. To our knowledge, only 1 previous case report of a single patient has reported the use of autologous bone pegs for the fixation of chondral fragments.[20] The report showed successful healing of a chondral fragment to bone in an adolescent, confirmed using MRI at 4 months and second-look arthroscopy at 12 months. Our study expands on these results with a larger sample size, longer follow-up, and MRI evaluation with MOCART score. A recent multicenter study by Fabricant et al[4] reported successful short-term (median of 12 months) outcomes for 15 pediatric patients with chondral fragment repair using various bioabsorbable screws. In their study, the median time to return to sports was 26.0 weeks, and 1 patient required the removal of a failed chondral fragment, similar to the results of our study. In patients in the Fabricant et al study who had postoperative MRI findings, 56% showed a restoration of cartilage contour and the resolution of subchondral edema; however, in our patients, 60% exhibited complete defect filling, and all showed a normal-appearing cartilage interface, homogeneous structure, and normal cartilage signal intensity. It is difficult to directly compare the MRI results of these 2 studies because the timing of evaluation was different (12 months for Fabricant et al vs 3.3 years in our study) and Fabricant et al did not report MOCART scores. Thus, it is unclear whether autologous tissue enhanced cartilage healing, resulting in the good MOCART scores for our cohort.

Even among 5 patients who retained the repaired fragments, all but 1 patient in our study showed subchondral abnormality including cyst (n = 1), sclerosis (n = 3), and edema-like signaling (n = 1). These observations are usually seen after bone marrow stimulation for the treatment of cartilage lesions.[3,16] Debridement of the cartilage lesion and penetration of subchondral bone for drilling and insertion of the bone pegs at the time of surgery might have resulted in the subchondral bone abnormalities in our study. A longer follow-up will be needed to determine the significance of the subchondral bone abnormality because subchondral bone changes may be associated with the failure of other cartilage repair techniques.[16,26]

We used autologous bone pegs to fix the chondral fragments to bone because we thought that there may be improvement in the biological healing between cartilage

TABLE 3
Characteristics of the Repaired Cartilage (MOCART Score)[a]

Patient	Time of MRI After Surgery, y	Degree of Defect Repair and Filling of the Defect	Integration to Border Zone	Surface of the Repair Tissue	Structure of the Repair Tissue	Signal Intensity of the Repair Tissue	Subchondral Lamina	Subchondral Bone	Adhesions	Effusion	Total MOCART Score
1	2.2	Complete	Complete	Intact	Homogeneous	Isointense	Not intact	Not intact	No	Absent	90
2	1.0	Complete	Complete	Intact	Homogeneous	Isointense	Not intact	Not intact	No	Absent	90
3	5.0	Complete	Complete	Intact	Homogeneous	Isointense	Not intact	Intact	No	Absent	95
4	3.9	Incomplete, >50%	Complete	Intact	Homogeneous	Isointense	Not intact	Not intact	No	Absent	80
6	1.9	Incomplete, >50%	Complete	Damaged <50% of the depth	Homogeneous	Isointense	Not intact	Not intact	No	Absent	70

[a]MOCART, magnetic resonance observation of cartilage repair tissue; MRI, magnetic resonance imaging.

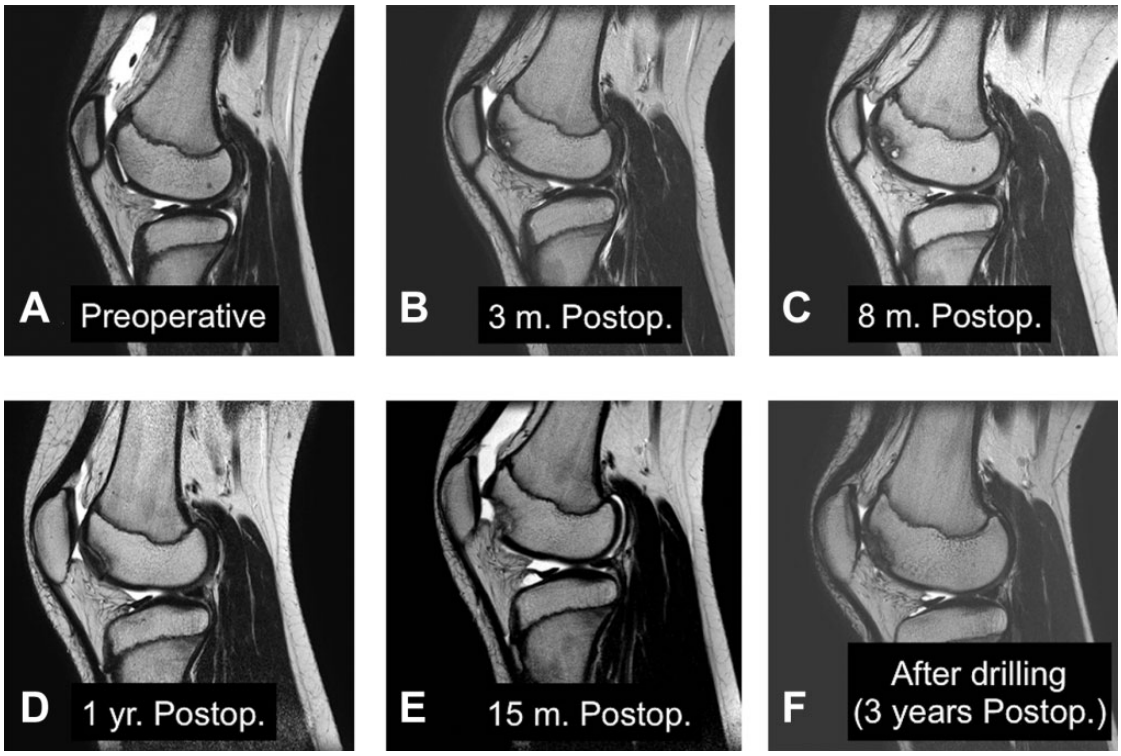

Figure 8. Pre- and postoperative magnetic resonance imaging (MRI) results of the patient with a failed chondral fixation (patient 5). (A) Preoperative MRI scan shows cartilage delamination in the lateral trochlear groove with the chondral fragment remaining within the defect. (B) Postoperative MRI scan at 3 months shows small cysts beneath the fixed chondral fragment. (C) Cystlike lesions enlarged at 8 months. (D) MRI scan at 1 year shows a high signal line between the fixed chondral fragment and underlying subchondral bone. (E) At 15 months postoperatively, the repaired chondral fragment had completely detached and displaced. (F) After the subsequent drilling procedure, the defect was covered with repair tissue (3 years after chondral fixation but 1.9 years after drilling).

tissue and underlying subchondral bone and there would be no need for subsequent screw removal. Moreover, several complications have been reported after the use of bioabsorbable screws.[6,29] The disadvantage of using autologous bone pegs is that it can be technically more demanding to produce bone pegs from harvested cortical bone and to insert these pegs because of insertional friction. Moreover, the method introduces potential morbidity of the bone harvest site, although no patient in our study exhibited any symptoms at the harvest site. Thus, further study will be needed to ascertain what method of fixation is optimal for the chondral fragment over a long-term follow-up.

In our cohort, all chondral injuries occurred during sports activities. In the adolescent patient, chondral injury is thought to result from twisting injury during sports activities, which was consistent with our patients' injuries. Twisting injury may impose shearing stress resulting in fracture between cartilage and subchondral bone. A previous biomechanical study has indicated that the interface between the cartilage and bone is weaker in adolescents than in adults.[8]

Although previous studies have suggested that patellar instability causes cartilage delamination in the trochlear groove,[4,34] no patient had a history of patellar dislocation or instability in our study. However, surgeons should consider the presence of patellar instability when lesions are located in the trochlear groove.

Overall, good clinical outcomes have been reported with a variety of fixation methods possibly because of high chondrocyte viability in the chondral fragment. Robinson et al[27] evaluated chondrocyte viability in osteochondral loose bodies in adolescents. In microscopic and histologic comparisons, those investigators found no significant difference in viability between the loose body (94%) and intercondylar notch (93%, control) groups. Pascual-Garrido et al[25] evaluated 5 patients with osteochondral fragments who underwent open reduction and internal fixation and noted no difference in chondrocyte viability between biopsies from the loose body and native cartilage. Although no study has assessed the viability of chondral fragment without a bony portion in the knee, a similar observation might be expected. High chondrocyte viability in the chondral fragment might have allowed for the production of extracellular matrix and integration to adjacent native cartilage, which led to the good clinical outcomes and good healing as determined on MRI scans in our study. In our case series, the preoperative duration of symptoms ranged from 0.4 to 4.9 months (mean, 1.7 months). Although several patients did not undergo surgery in the acute phase, the results were promising possibly because chondrocyte viability was maintained by nutrition from the synovial fluid[30,32] after the delamination. Thus, it appears that chronic injury is not a contraindication to this surgery as long as the fragment still fits the defect; other authors also have suggested that there is no time limit to this surgery.[31]

In our study, 1 patient experienced failure at 1.3 years after surgery. The fragment size was 9 cm^2 in the lateral trochlear groove, the largest fragment in this cohort. A number of previous studies have shown that larger chondral lesions resulted in unfavorable outcomes in patients who underwent cartilage repair.[17,23,24] The risk factors for failure after this procedure need to be determined by future studies. This patient underwent removal of the unhealed chondral fragment and a subsequently successful drilling procedure that allowed for return to sports without limitations. Thus, attempted direct fixation of purely chondral fragments using autologous bone pegs should be primarily considered because this procedure does not appear to negatively affect any salvage cartilage repair procedure.

The strengths of this study are that all patients with retained fixed fragments underwent postoperative MRI to evaluate the healing of the cartilage fragment and that we present intermediate-term results. Nevertheless, this study has a number of limitations. First, this was a small case study with no control group. However, this injury is rare, making it difficult to include a control group. Second, we were unable to compare preoperative and postoperative patient-reported outcomes, as these data are not obtained consistently in our clinical practice. Third, we did not conduct a histological assessment to ascertain whether there were any bony portions in the chondral fragment. However, the definition of "chondral-only" used in our study is consistent with that used in the previous studies and in common clinical practice.[2,4,10,12,20,34]

CONCLUSION

The fixation of chondral fragments in adolescents using autologous bone pegs provided successful results with good quality of repaired tissue as noted on MRI scans. The attempt to restore joint congruity by fixation of chondral fragments should be considered for this type of injury in young and active patients. Further study will be needed to validate our findings and to ascertain whether this technique prevents progression to osteoarthritis.

ACKNOWLEDGMENT

The authors thank Shunji Soma and Shogo Ato for preparation of the images.

REFERENCES

1. Brittberg M, Lindahl A, Nilsson A, Ohlsson C, Isaksson O, Peterson L. Treatment of deep cartilage defects in the knee with autologous chondrocyte transplantation. *N Engl J Med*. 1994;331(14):889-895.
2. Chan CM, King JJ III, Farmer KW. Fixation of chondral fracture of the weight-bearing area of the lateral femoral condyle in an adolescent. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(6):1284-1287.
3. Demange MK, Minas T, von Keudell A, Sodha S, Bryant T, Gomoll AH. Intralesional osteophyte regrowth following autologous chondrocyte implantation after previous treatment with marrow stimulation technique. *Cartilage*. 2017;8(2):131-138.
4. Fabricant PD, Yen YM, Kramer DE, et al. Fixation of traumatic chondral-only fragments of the knee in pediatric and adolescent athletes: a retrospective multicenter report. *Orthop J Sports Med*. 2018; 6(2):2325967117753140.
5. Flachsmann R, Broom ND, Hardy AE, Moltschaniwskyj G. Why is the adolescent joint particularly susceptible to osteochondral shear fracture? *Clin Orthop Relat Res*. 2000;381:212-221.
6. Friederichs MG, Greis PE, Burks RT. Pitfalls associated with fixation of osteochondritis dissecans fragments using bioabsorbable screws. *Arthroscopy*. 2001;17(5):542-545.
7. Gortz S, Bugbee WD. Allografts in articular cartilage repair. *J Bone Joint Surg Am*. 2006;88(6):1374-1384.
8. Hangody L, Fules P. Autologous osteochondral mosaicplasty for the treatment of full-thickness defects of weight-bearing joints: ten years of experimental and clinical experience. *J Bone Joint Surg Am*. 2003; 85(suppl 2):25-32.
9. Insall J. The Pridie debridement operation for osteoarthritis of the knee. *Clin Orthop Relat Res*. 1974;101:61-67.
10. Levy AS, Lohnes J, Sculley S, LeCroy M, Garrett W. Chondral delamination of the knee in soccer players. *Am J Sports Med*. 1996;24(5): 634-639.
11. Linden B. Osteochondritis dissecans of the femoral condyles: a long-term follow-up study. *J Bone Joint Surg Am*. 1977;59(6):769-776.
12. Maletius W, Lundberg M. Refixation of large chondral fragments on the weight-bearing area of the knee joint: a report of two cases. *Arthroscopy*. 1994;10(6):630-633.
13. Mankin HJ. The response of articular cartilage to mechanical injury. *J Bone Joint Surg Am*. 1982;64(3):460-466.
14. Marlovits S, Singer P, Zeller P, Mandl I, Haller J, Trattnig S. Magnetic resonance observation of cartilage repair tissue (MOCART) for the evaluation of autologous chondrocyte transplantation: determination

of interobserver variability and correlation to clinical outcome after 2 years. *Eur J Radiol*. 2006;57(1):16-23.
15. Marlovits S, Striessnig G, Resinger CT, et al. Definition of pertinent parameters for the evaluation of articular cartilage repair tissue with high-resolution magnetic resonance imaging. *Eur J Radiol*. 2004; 52(3):310-319.
16. Minas T, Gomoll AH, Rosenberger R, Royce RO, Bryant T. Increased failure rate of autologous chondrocyte implantation after previous treatment with marrow stimulation techniques. *Am J Sports Med*. 2009;37(5):902-908.
17. Minas T, Von Keudell A, Bryant T, Gomoll AH. The John Insall Award: a minimum 10-year outcome study of autologous chondrocyte implantation. *Clin Orthop Relat Res*. 2014;472(1):41-51.
18. Murray JR, Chitnavis J, Dixon P, et al. Osteochondritis dissecans of the knee: long-term clinical outcome following arthroscopic debridement. *Knee*. 2007;14(2):94-98.
19. Nakamura N, Horibe S, Iwahashi T, Kawano K, Shino K, Yoshikawa H. Healing of a chondral fragment of the knee in an adolescent after internal fixation: a case report. *J Bone Joint Surg Am*. 2004;86(12): 2741-2746.
20. Nakayama H, Yoshiya S. Bone peg fixation of a large chondral fragment in the weight-bearing portion of the lateral femoral condyle in an adolescent: a case report. *J Med Case Rep*. 2014;8:316.
21. Ogura T, Bryant T, Minas T. Long-term outcomes of autologous chondrocyte implantation in adolescent patients. *Am J Sports Med*. 2017; 45(5):1066-1074.
22. Ogura T, Mosier BA, Bryant T, Minas T. A 20-year follow-up after first-generation autologous chondrocyte implantation. *Am J Sports Med*. 2017;45(12):2751-2761.
23. Pareek A, Carey JL, Reardon PJ, Peterson L, Stuart MJ, Krych AJ. Long-term outcomes after autologous chondrocyte implantation: a systematic review at mean follow-up of 11.4 years. *Cartilage*. 2016; 7(4):298-308.
24. Pareek A, Reardon PJ, Maak TG, Levy BA, Stuart MJ, Krych AJ. Long-term outcomes after osteochondral autograft transfer: a systematic review at mean follow-up of 10.2 years. *Arthroscopy*. 2016;32(6): 1174-1184.
25. Pascual-Garrido C, Tanoira I, Muscolo DL, Ayerza MA, Makino A. Viability of loose body fragments in osteochondritis dissecans of the knee: a series of cases. *Int Orthop*. 2010;34(6):827-831.
26. Pestka JM, Bode G, Salzmann G, Sudkamp NP, Niemeyer P. Clinical outcome of autologous chondrocyte implantation for failed microfracture treatment of full-thickness cartilage defects of the knee joint. *Am J Sports Med*. 2012;40(2):325-331.
27. Robinson S, Kramer J, Shelton T, Merriman J, Haus B. Assessment of cartilage growth after biopsy of osteochondral loose bodies in adolescent knees for use in autologous chondrocyte implantation. *J Pediatr Orthop*. 2020;40(3):110-113.
28. Sanders TL, Pareek A, Obey MR, et al. High rate of osteoarthritis after osteochondritis dissecans fragment excision compared with surgical restoration at a mean 16-year follow-up. *Am J Sports Med*. 2017; 45(8):1799-1805.
29. Scioscia TN, Giffin JR, Allen CR, Harner CD. Potential complication of bioabsorbable screw fixation for osteochondritis dissecans of the knee. *Arthroscopy*. 2001;17(2):e7.
30. Sharma AR, Jagga S, Lee SS, Nam JS. Interplay between cartilage and subchondral bone contributing to pathogenesis of osteoarthritis. *Int J Mol Sci*. 2013;14(10):19805-19830.
31. Siparsky PN, Bailey JR, Dale KM, Klement MR, Taylor DC. Open reduction internal fixation of isolated chondral fragments without osseous attachment in the knee: a case series. *Orthop J Sports Med*. 2017;5(3):2325967117696281.
32. Sophia Fox AJ, Bedi A, Rodeo SA. The basic science of articular cartilage: structure, composition, and function. *Sports Health*. 2009; 1(6):461-468.
33. Steadman JR, Briggs KK, Rodrigo JJ, Kocher MS, Gill TJ, Rodkey WG. Outcomes of microfracture for traumatic chondral defects of the knee: average 11-year follow-up. *Arthroscopy*. 2003;19(5):477-484.
34. Uchida R, Toritsuka Y, Yoneda K, Hamada M, Ohzono K, Horibe S. Chondral fragment of the lateral femoral trochlea of the knee in adolescents. *Knee*. 2012;19(5):719-723.