# Fixation of Traumatic Chondral-Only Fragments of the Knee in Pediatric and Adolescent Athletes

## A Retrospective Multicenter Report

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**Background:** While traditional biological principles have suggested that fragments consisting of cartilage alone cannot be re-affixed to bone with expectable long-term healing, case reports of successful healing after fixation in younger patients indicate that this concept remains incompletely explored.

**Purpose:** To evaluate the presenting features, techniques, healing rates, and clinical and radiological results in a cohort of pediatric and adolescent athletes who underwent fixation of traumatic chondral-only fragments in the knee.

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

**Methods:** Patient registries at 2 tertiary care children's hospitals were reviewed to identify patients ≤18 years old who underwent fixation of a "chondral-only" fragment in the knee, defined as the inability to visualize the fragment on injury radiographs or discern bone on the articular portion of a fragment intraoperatively. The mechanism of injury, fragment features, fixation technique, and postoperative clinical course, including timing of sports clearance, healing on postoperative magnetic resonance imaging (MRI), and any complications or reoperations, were assessed.

**Results:** Fifteen patients with a median age at surgery of 12.7 years (interquartile range [IQR], 11.7-14.2 years) and median follow-up of 12.0 months (IQR, 6.0-19.2 months) were analyzed. All patients sustained an acute knee injury before surgery. The injured sites, as assessed on MRI, were the patella (n = 6), trochlea (n = 5), and lateral femoral condyle (n = 4). The median fragment surface area was 492.0 mm$^2$ (IQR, 400.0-787.5 mm$^2$). Fixation with bioabsorbable implants was performed in all patients at a median of 1.6 weeks (IQR, 1.0-2.6 weeks) after the injury. One patient (7%) sustained a fall 8 weeks postoperatively, requiring secondary surgery for excision of a dislodged fragment, and 1 patient (7%) underwent unrelated patellar stabilization surgery 3.4 years postoperatively, at which time the fragment was found to be stable. MRI was performed in 9 of 14 patients with retained fragments (median, 12.0 months postoperatively), with 5 patients (56%) showing restoration of the cartilage contour and the resolution of subchondral edema; 2 patients showed thinning but intact cartilage, 1 had cartilage thickening, and 1 had subchondral edema, fissuring, and cystic changes. The median time to return to sports for all 15 patients was 26.0 weeks (IQR, 22.8-40.9 weeks), including 2 patients who required second surgery and returned to sports at 26.1 and 191.1 weeks.

**Conclusion:** Fixation of traumatic chondral-only fragments using bioabsorbable implants may result in successful short-term healing in the majority of pediatric and adolescent athletes.

**Keywords:** cartilage; patellofemoral; dislocation; shear

An acute knee injury resulting from patellar instability episodes, forced hyperextension, or direct blows to the knee may occasionally lead to the generation of osteochondral fragments originating from the patella, trochlea, or femoral condyle.[6,14,26,31,33] In young, active patients who sustain intra-articular osteochondral shear fractures, attempted fixation is recommended in the acute setting, provided the adequately sized fragment contains substantial bony tissue.[6,14] With reduction and rigid fixation, this may result in direct bone-to-bone healing, allowing for preservation of the native joint surface.

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While bone-to-bone healing may occur even in the intra-articular setting, traditional biological principles suggest that fragments consisting of cartilage alone cannot be successfully reaffixed to bone because of the poor healing potential.[3,30] Despite this, there exists controversy in light of recent case reports[16,21] that included follow-up magnetic resonance imaging (MRI), second-look arthroscopic surgery, and healed fragment core biopsy demonstrating successful fixation of a chondral-only fragment.[21] Currently, there is a paucity of data to guide the orthopaedic surgeon who faces the scenario of an intra-articular cartilage-only fragment in the setting of acute knee injuries. Such instances are particularly challenging in the pediatric population, in whom long-term data are minimal regarding the rates and severity of degenerative joint disease after such injuries, but in whom decades of future impact activities are expected in an active population. Anderson and Pagnani[1] demonstrated rapid progression toward debilitating osteoarthritis in patients with osteochondritis dissecans in whom fragment excision alone was performed. While fragment excision and cartilage resurfacing techniques such as microfracture,[8,28] osteoarticular autograft transfer,[8] autologous chondrocyte implantation,[17,19] and osteochondral allografts[20] have been explored,[9,18] the best evidence for these techniques is also primarily limited to adult populations. No case series to date has explored the possibility of chondral-only fragment fixation in the young athlete, in large part because of the ingrained notion that cartilage tissue itself, which lacks a blood supply, does not undergo healing after an injury.[4,10,22]

Despite the lack of data on the subject, surgeons at the 2 study institutions (Boston Children's Hospital and Children's Hospital of Philadelphia) have previously performed fixation of large, structurally intact, chondral-only fragments in a number of young patients in an attempt to try to preserve the native articular cartilage. Therefore, the purpose of the current study was to evaluate the presenting features, techniques, rates of healing, clinical course, and radiological results in a cohort of youth athletes who underwent fixation of chondral-only fragments. The study hypothesis was that this retrospective investigation would demonstrate the relative safety and feasibility of chondral-only fragment fixation, such that a prospective assessment of the long-term implications on the preservation of function and joint health should be pursued on a larger scale.

## METHODS

Institutional review board–approved departmental clinical databases at 2 regional, tertiary-care children's hospitals were queried to identify patients ≤18 years old who underwent fixation of a chondral-only fragment in the knee. All patients had standard 4-view radiographs at the time of the initial consultation (anteroposterior, lateral, tunnel, Merchant). Additionally, MRI sequences were obtained in all patients preoperatively. They varied by the institution in which they were conducted but at a minimum included axial, coronal, and sagittal proton density–weighted and T2-weighted sequences with fat suppression. For the purposes of the current study, a chondral-only fragment was defined as the inability to visualize the fragment on radiographs or MRI and discern bone on the articular portion of a fragment intraoperatively. Additional inclusion criteria for the study were age ≤18 years at the time of surgery, documentation of a previous traumatic knee injury felt to be the cause of the chondral fragment, and treatment of the chondral fragment with internal fixation (rather than excision and cartilage resurfacing techniques). Eighteen patients were identified for potential inclusion. After an additional independent review of radiographs and operative dictations by a dual fellowship-trained pediatric orthopaedic/sports medicine attending surgeon, 3 patients were excluded for the presence of bone on an articular fragment. This left a cohort of 15 patients ≤18 years old who underwent internal fixation of an acutely sustained chondral-only shear fragment. All patients had participated in at least 1 organized or recreational sport or activity before the injury. One patient was previously included in a case report.[16]

The mechanism of injury, fragment features, fixation technique, and postoperative clinical course, including timing of sports clearance, healing on postoperative MRI, and any complications or reoperations, were assessed. Descriptive statistics are reported as medians and interquartile ranges (IQRs) to minimize the skew effect of outliers, which is of concern in reports of rare conditions. No a priori power calculation was performed because (1) this is a rare condition necessitating the use of all available patients and (2) this is a descriptive cohort study without direct statistical subgroup comparison.[13]

## RESULTS

The median age at the time of surgery was 12.7 years (IQR, 11.7-14.2 years), and the median follow-up was 12.0 months (IQR, 6.0-19.2 months). Moreover, 73% (11/15) of the cohort was male. Thirteen patients had open physes, 1 had closing physes, and 1 had closed physes. All patients sustained a documented knee injury before surgery, including self-reported twisting/patellar instability episodes (n = 9), a fall onto a flexed knee (n = 4), or a hyperextension injury (n = 2). Injury sites included the patella (n = 6), trochlea

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(n = 5), and lateral femoral condyle (n = 4). The median fragment surface area was 492.0 $mm^2$ (IQR, 400.0-787.5 $mm^2$) based on intraoperative measurements. All chondral fragments were absent of bone, with the exception of 1 patient with a 2 × 6 × 1–mm portion of bone on the nonarticular segment of a 30 × 21–mm chondral fragment, which was not visible on 3 radiographic views of the knee. Arthrotomy, with (n = 13) or without (n = 2) preceding arthroscopic surgery, was performed in all patients, which occurred at a median of 1.6 weeks (IQR, 1.0-2.6 weeks) after the injury. The lesion bed was prepared with gentle debridement down to bleeding bone and subchondral drilling. Fixation implants included bioabsorbable tacks alone (n = 8), bioabsorbable tacks and a bioabsorbable screw (n = 1), bioabsorbable tacks/screw and bioabsorbable suture (n = 3), absorbable suture alone (n = 1), absorbable suture with suture anchors (n = 1), and bioabsorbable tacks and absorbable suture with suture anchors (n = 1). Bioabsorbable tacks and screws were composed of polylactic acid, and absorbable suture was made of 6-0 braided polyglactin. Three of 15 patients were treated with the application of fibrin glue to the repair site after fixation, which was allowed to set for 5 minutes. Illustrative case examples are presented in Figures 1, 2, and 3. Six of the 9 patients who sustained a patellofemoral instability event underwent concurrent medial retinacular reefing, imbrication, plication, or repair, with concurrent lateral release in 5 of the 6 patients.

One patient (7%) sustained a fall from crutches onto a flexed knee 8 weeks postoperatively, dislodging the repaired fragment and requiring secondary surgery for excision of the fragment. One patient (7%) with an original patellofemoral dislocation injury who underwent isolated fragment fixation at the time of index surgery subsequently required tibial tubercle osteotomy for continued patellar instability 3.4 years postoperatively, at which time the fixed fragment was found to be stable. Finally, 1 patient (7%) required a reoperation 1 year after the index procedure to remove 2 small, unrelated loose bodies of indeterminate origin; during second-look arthroscopic surgery, the original chondral fixation site appeared smooth without step-off, delamination, or softening (Figure 2).

Postoperative MRI to assess the fragment was performed in 9 of 14 patients with a retained fixed fragment at a median of 12.0 months postoperatively, with 5 (56%) showing restoration of the cartilage contour and complete or near-complete resolution of subchondral edema. Two of 9 patients demonstrated thinning of cartilage (associated with an intact articular contour and advancement of subchondral bony tissue into the level of the deep zone of cartilage, relative to the adjacent/noninjured cartilage), 1 demonstrated cartilage thickening with slightly recessed subchondral bone and an intact articular surface contour, and 1 of 9 had subchondral edema, fissuring, and cystic changes of the patellar lesion. All 15 patients returned to sports and activities a median of 26.0 weeks (IQR, 22.8-40.9 weeks) after surgery. Preoperatively, 14 patients competed in ≥1 team sports, including football, basketball, water polo, volleyball, track and field, baseball, and gymnastics. One patient was training to become a firefighter through strength- and employment-based training. Twelve of 14 patients (86%) who participated in team

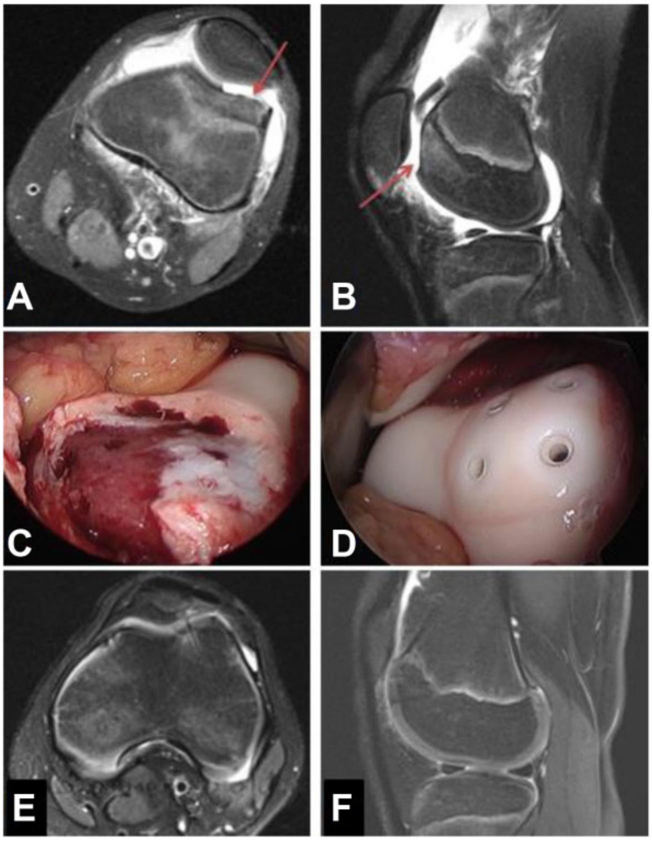


**Figure 1.** An 11-year-old male patient fell onto a flexed knee. (A) Axial and (B) sagittal T2-weighted turbo spin echo (TSE) magnetic resonance imaging (MRI) sequences with fat suppression (Magnetom Sonata 1.5 T; Siemens) reveal a loose chondral fragment from the lateral femoral condyle/trochlea with maintenance of subchondral bone at the donor site (arrows). Intraoperative photographs show (C) chondral defect on the lateral trochlea and (D) fixation using absorbable tacks and fibrin glue. (E) Axial and (F) sagittal T2-weighted TSE MRI sequences with fat suppression (Magnetom Skyra 3 T; Siemens) obtained 4.5 months postoperatively show early fragment integration and resolution of bone marrow edema.

sports preoperatively returned to the same sport(s) postoperatively and were competing at or above the preoperative level of competition at final follow-up. One patient who played soccer and basketball preoperatively returned to nonimpact recreational sports (cycling and yoga). The other patient who did not return to the same level of competitive sports played football preoperatively and returned to recreational fitness activities and working with a personal trainer postoperatively. The 1 patient who was undergoing firefighter training preoperatively returned to training at the same level and successfully earned his firefighter certification.

## DISCUSSION

In the current study, most of the pediatric or adolescent athletes demonstrated an uncomplicated early postoperative

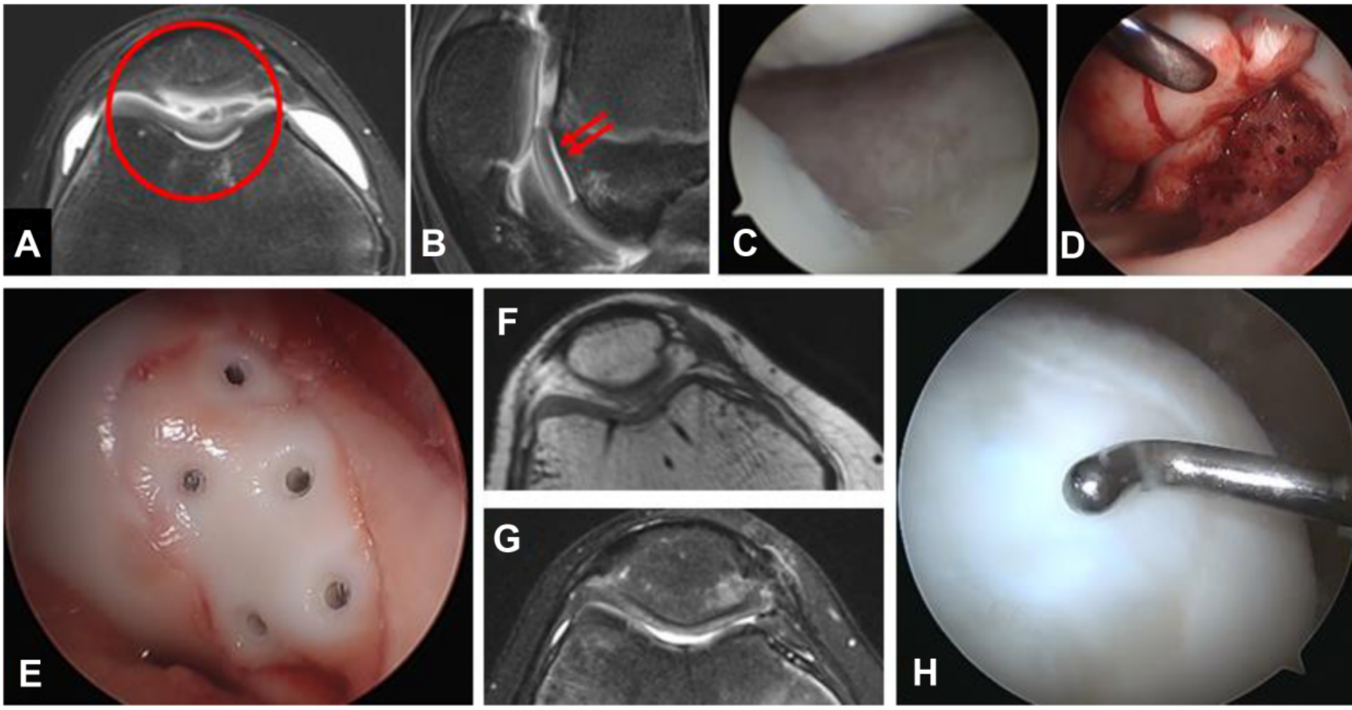


**Figure 2.** A 12-year-old male patient fell onto a flexed knee and presented with complaints of dull, achy anterior knee pain. (A) Axial and (B) sagittal T2-weighted turbo spin echo (TSE) magnetic resonance imaging (MRI) sequences with fat suppression (Magnetom Verio 3 T; Siemens) demonstrate a chondral-only shear fracture of the trochlea (circle), with an intact tidemark at the donor site (arrows). (C) Arthroscopic surgery and (D) arthrotomy revealed no viable bone on the back of the cartilage flap, which was treated with (E) drilling of the base and fixation with absorbable tacks. Three-month postoperative (F) axial proton density–weighted TSE and (G) axial T2-weighted TSE MRI sequences with fat suppression (Magnetom Verio 3 T) reveal restoration of the cartilage contour and early healing with the resolution of edema. (H) Second-look arthroscopic surgery at 12 months postoperatively for the removal of a small loose body of indeterminate origin revealed stable cartilage with an intact, healed interface between the fragment and donor site.

course and returned to sports after acute fixation of cartilage-only fragments following traumatic knee injuries. All 15 patients returned to sports and activities at a median time of around 6 months, with a median follow-up of 12 months. Although this represents a short-term case series of a rare condition, it suggests that fixation of acute cartilage-only fragments in children may be associated with at least substantial degrees of healing, even in the absence of any bone appreciated on the traumatic fragment, as noted on preoperative radiographs and intraoperative inspection. Given this possibility of successful healing, the clear advantage of fragment fixation is that it allows for the possibility of native articular restoration. The disadvantage is that several different scenarios exist for potential secondary surgeries in such cases, including implant prominence and subsequent chondral injuries (of other areas of the joint, with which the fragment articulates), implant breakage and/or migration, and failure of healing.[5,7,12,25,29,32,34] However, while 1 patient with failed healing was seen in the current series, no implant-related complications were seen in the other 14 patients, despite the need to place such implants more superficially than is commonly performed for fixation of osteochondral fragments with bioabsorbable implants. Fixation surgery was performed in these cases with the fallback option that if healing failed or subsequent trauma redisplaced the fragment, more advanced cartilage resurfacing techniques such as microfracture, autologous or allograft osteoarticular transfer, or autologous chondrocyte implantation remained secondary or salvage options. Furthermore, in the event of partial fragment healing, these salvage procedures would involve restoration of a smaller joint surface area.

Limitations of the current study are inherent to its small sample size, short-term follow-up, and retrospective study design. Despite having a limited number of patients, to date, only 1 detailed case report has emerged discussing chondral-only fixation in the knee,[21] and a recent multicenter investigation of osteochondral injuries in pediatric patients yielded only 14 patients.[6] This study expands upon the existing literature by reporting on a similarly sized series, but with chondral-only fixation of intra-articular knee fragments, which represents a much rarer entity and may provide retrospective data upon which to establish a framework for future comparative studies. Such studies may stem from multicenter prospective registries, which are ideal for studying rare conditions. While patients in the current study were included from only 2 institutions, they represent the collective practices of 7 orthopaedic surgeons

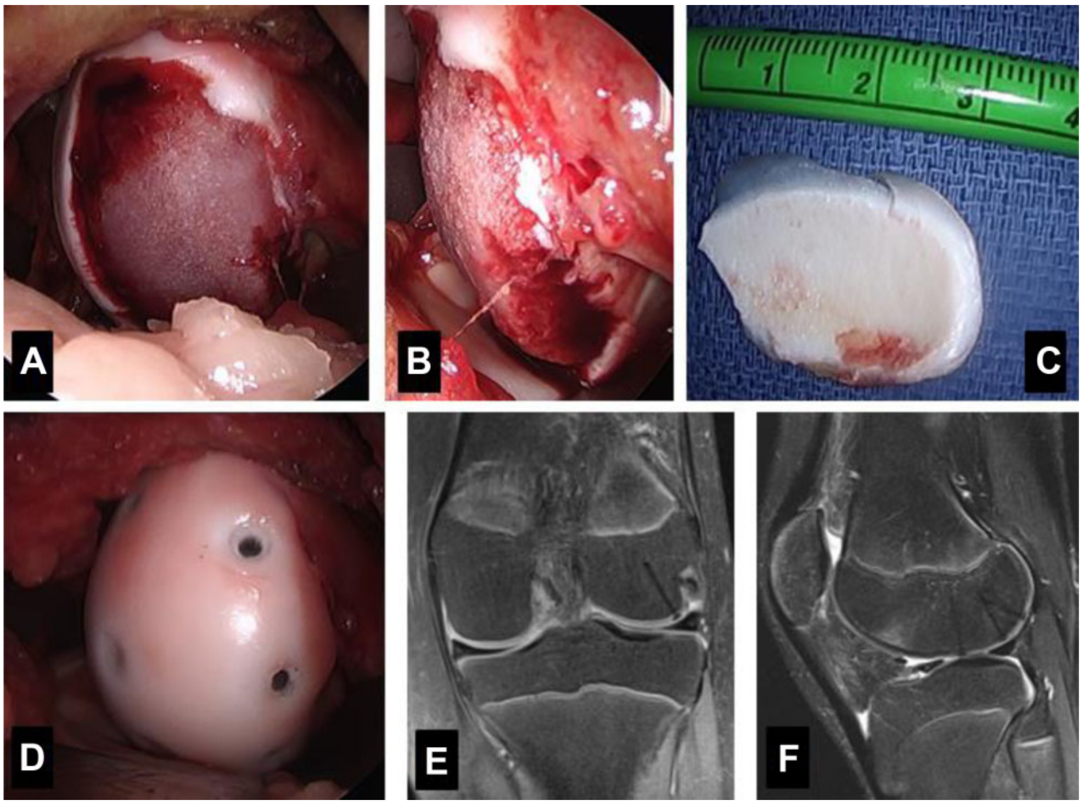


**Figure 3.** A 12-year-old female gymnast sustained a twisting injury on landing, resulting in a large chondral shear injury of the lateral femoral condyle. (A) Frontal and (B) side intraoperative images reveal a denuded lateral femoral condyle with intact subchondral bone. (C) The chondral fragment measured 21 mm $\times$ 30 mm, had no bone, and was comprised only of articular cartilage. (D) It was anatomically repaired using absorbable tacks. (E) Coronal and (F) sagittal T2-weighted turbo spin echo magnetic resonance imaging sequences with fat suppression (Magnetom Verio 3 T; Siemens) obtained 3 months postoperatively reveal early healing with an intact cartilage contour with no evidence of tack migration.

and the use of a variety of different absorbable implant options. This affords some generalizability with regard to the nuances of surgical techniques, despite being from a limited number of centers.

Another limitation of the current study is that not all patients had undergone postoperative MRI to evaluate fragment healing. Many health insurance companies will not approve postoperative MRI in asymptomatic patients. Because of this, however, those who did not undergo postoperative MRI likely represent a group that would have had improved imaging findings; therefore, the MRI data reported in the current study are likely an underestimate of the rate of MRI fragment healing. Moreover, most patients had moved on to college or a professional career, and we were unable to perform longer term objective clinical examinations or obtain patient-reported outcomes. This study would have benefited from a long-term follow-up, given the subtle abnormalities noted on postoperative MRI. While it is unclear how durable the results of the current study are in the long term, primary outcome analysis of clinical and radiographic lesion healing was excellent, allowing for the preservation of native articular surface tissue.

An additional limitation is that although biopsy of the cartilage fragment at the time of surgery would have provided conclusive evidence as to the presence of bone versus the existence of a chondral-only fragment, this strategy may not be practical because of the restraints on intraoperative time and resources that would be required to obtain a definitive pathological diagnosis. More importantly, obtaining sufficient tissue for biopsy would compromise the integrity of the fragments, which have been deemed to be within the important weightbearing zones of the articular surface of the knee. Therefore, for this study, we defined "chondral-only" as the lack of bone on preoperative radiographs and on the articular portion of the fragment upon intraoperative inspection. Preoperative radiographs were independently reviewed during the inclusion/exclusion process to ensure strict adherence to this definition, and operative notes explicitly stated that there was a complete lack of osseous tissue on the fragment, with the exception of a nonarticular segment of bone that constituted 2% of the surface area of a large chondral fragment. As a result, the current series may be a relative underestimate of the incidence of such cases, given that surgeons may not have documented the details of other chondral-only fragments, which could not be ruled out as osteochondral fragments in the study's chart review process. Moreover, we had encountered descriptions of many fragments that had “minimal” bone or <5 mm of bone on the backside of the fragment, in any dimension. While healing of such fragments would be expected to be superior to the ones described in the current series, many of these “minimal” bone fragments may have effectively acted as “chondral-only” fragments in which substantial portions of cartilage-to-bone healing occurred and had favorable clinical outcomes.

Nakamura et al[21] presented a case report of successful healing of a chondral fragment to bone in an 11-year-old child who sustained a twisting injury while kicking a soccer ball. Histology at the time of index surgery revealed viable chondrocytes and the absence of bone in the fragment, which was fixed to the trochlea using 4 bioabsorbable pins. Second-look arthroscopic surgery and biopsy at the center of the lesion 6 months later revealed normal deep and superficial cartilage zone microarchitecture with restoration of the osteochondral junction. The patient was cleared for sports at that time, and follow-up MRI 33 months after fragment fixation showed complete lesion healing with pin resorption and no discernable boundary between the fragment and adjacent uninjured cartilage. At that time, the patient demonstrated full range of motion, no swelling, and full symptom-free activity.

One of the contributing reasons for the successful treatment of these chondral-only fragments with acute fixation is likely related to the discrepancy between the practical and histological definitions of the cartilage-only fragment, particularly with respect to anatomic differences between youth and adult patients. In the adult osteochondral junction, the tidemark distinguishes the deep cartilaginous zone from the calcified cartilage layer, which is the most superficial layer of bone. At this junction, there is an abrupt transition in stiffness from low (cartilage) to high (bone) because of differences in proteoglycan content.[27] Furthermore, collagen fibrils in the calcified cartilage layer are oriented perpendicularly to the cartilage, along the plane of motion of the joint.[24,27] It makes sense, therefore, that this well-defined cartilage-bone junction represents a weak point, thus resulting in more chondral-only injuries after a shearing mechanism in adults. Conversely, in the growing skeleton, a secondary physis surrounds the secondary ossification center(s) in the knee, which is responsible for outward growth of the epiphysis.[15] This secondary physis is deep to the tidemark in skeletally immature knees[15] and has similar MRI characteristics to primary physeal tissue. Because physeal tissue represents a known weak point in the growing skeleton,[11,23] a chondral-only shear injury of the knee in a skeletally immature patient may be in fact more likely to contain some osseous tissue. This may also be true for those who have recently reached skeletal maturity; chondral shear injuries may displace with a microscopic layer of bone that is imperceptible on plain radiographs or visual inspection at the time of surgery. This concept has been shown in a bovine model in vitro, which indicates that adult cartilage delaminates within a well-defined region, whereas immature tissue separates in subchondral bone, where fingers of cartilage tissue penetrate more deeply and create a less well-demarcated osteochondral transition zone.[2] The existence of microscopic amounts of bone in juvenile shear injuries may be sufficient to promote healing, as it is known that chondrocytes alone have poor intrinsic potential to heal to bone, regardless of maturation stage.[30] This may partially explain the high clinical healing rates noted in this study. Our results are comparable to those of a recent multicenter cohort study that investigated fixation of osteochondral fragments of the patella and lateral condyle/trochlear region in pediatric and adolescent patients. Chotel et al[6] described 14 patients with a mean age of 12.9 years in whom osteochondral fragments were fixed to the donor site (the patella in 5 and the lateral condyle/trochlear region in 9 patients) at a mean of 5.2 days after the injury using a variety of absorbable and metal implants. No patient underwent revision surgery for fixation failure, and 3 patients (21%) underwent secondary surgery for patellar stabilization at a mean follow-up of 30 months. The clinical outcomes of the current study are similar, despite the lack of macroscopic amounts of bone on all fracture fragments and an injury-to-surgery interval of twice the time of the study by Chotel et al.[6] Clearly, however, a longer term follow-up of both categories of injury, and their various treatments, is warranted to better understand the implications on joint preservation into the older adolescent and young adult years.

## CONCLUSION

There is minimal literature to guide the treatment of traumatic, chondral-only articular injuries of the knee. The results of the current study suggest that acute fixation of chondral-only fragments using bioabsorbable implants may be considered in pediatric and adolescent athletes, with favorable short-term radiological and clinical results suggesting fragment healing and a full return to sports in this small series. Fixation of large, structurally intact chondral-only fragments may be a viable option for attempting to preserve the native articular cartilage in young patients.

## REFERENCES


1. Anderson AF, Pagnani MJ. Osteochondritis dissecans of the femoral condyles: long-term results of excision of the fragment. *Am J Sports Med*. 1997;25(6):830-834.
2. Broom ND, Oloyede A, Flachsmann R, et al. Dynamic fracture characteristics of the osteochondral junction undergoing shear deformation. *Med Eng Phys*. 1996;18(5):396-404.
3. Buckwalter JA. Articular cartilage: injuries and potential for healing. *J Orthop Sports Phys Ther*. 1998;28(4):192-202.
4. Buckwalter JA, Mankin HJ. Articular cartilage: degeneration and osteoarthritis, repair, regeneration, and transplantation. *Instr Course Lect*. 1998;47:487-504.
5. Camathias C, Gogus U, Hirschmann MT, et al. Implant failure after biodegradable screw fixation in osteochondritis dissecans of the knee in skeletally immature patients. *Arthroscopy*. 2015;31(3):410-415.
6. Chotel F, Knorr G, Simian E, et al. Knee osteochondral fractures in skeletally immature patients: French multicenter study. *Orthop Traumatol Surg Res*. 2011;97(suppl 8):S154-S159.
7. Grimm NL, Ewing CK, Ganley TJ. The knee: internal fixation techniques for osteochondritis dissecans. *Clin Sports Med*. 2014;33(2):313-319.
8. Gudas R, Kalesinskas RJ, Kimtys V, et al. A prospective randomized clinical study of mosaic osteochondral autologous transplantation

versus microfracture for the treatment of osteochondral defects in the knee joint in young athletes. *Arthroscopy*. 2005;21(9):1066-1075.
9. Harris JD, Brophy RH, Siston RA, et al. Treatment of chondral defects in the athlete's knee. *Arthroscopy*. 2010;26(6):841-852.
10. Hunziker EB. Articular cartilage repair: basic science and clinical progress. A review of the current status and prospects. *Osteoarthritis Cartilage*. 2002;10(6):432-463.
11. Iannotti JP. Growth plate physiology and pathology. *Orthop Clin North Am*. 1990;21(1):1-17.
12. Kocher MS, Czarnecki JJ, Andersen JS, et al. Internal fixation of juvenile osteochondritis dissecans lesions of the knee. *Am J Sports Med*. 2007;35(5):712-718.
13. Kocher MS, Zurakowski D. Clinical epidemiology and biostatistics: a primer for orthopaedic surgeons. *J Bone Joint Surg Am*. 2004;86-A(3): 607-620.
14. Kramer DE, Pace JL. Acute traumatic and sports-related osteochondral injury of the pediatric knee. *Orthop Clin North Am*. 2012;43(2): 227-236, vi.
15. Laor T, Jaramillo D. MR imaging insights into skeletal maturation: what is normal? *Radiology*. 2009;250(1):28-38.
16. Lawrence JTR, Trivedi V, Ganley TJ. All arthroscopic suture-bridge fixation of a delaminated chondral fragment. *UPOJ*. 2011;21:83-86.
17. Micheli L, Curtis C, Shervin N. Articular cartilage repair in the adolescent athlete: is autologous chondrocyte implantation the answer? *Clin J Sport Med*. 2006;16(6):465-470.
18. Mithoefer K, McAdams TR, Scopp JM, et al. Emerging options for treatment of articular cartilage injury in the athlete. *Clin Sports Med*. 2009;28(1):25-40.
19. Mithoefer K, Minas T, Peterson L, et al. Functional outcome of knee articular cartilage repair in adolescent athletes. *Am J Sports Med*. 2005;33(8):1147-1153.
20. Murphy RT, Pennock AT, Bugbee WD. Osteochondral allograft transplantation of the knee in the pediatric and adolescent population. *Am J Sports Med*. 2014;42(3):635-640.
21. Nakamura N, Horibe S, Iwahashi T, et al. Healing of a chondral fragment of the knee in an adolescent after internal fixation: a case report. *J Bone Joint Surg Am*. 2004;86-A(12):2741-2746.
22. Newman AP. Articular cartilage repair. *Am J Sports Med*. 1998;26(2): 309-324.
23. Ogden JA, Ganey T, Light TR, et al. The pathology of acute chondro-osseous injury in the child. *Yale J Biol Med*. 1993;66(3): 219-233.
24. Redler I, Mow VC, Zimny ML, et al. The ultrastructure and biomechanical significance of the tidemark of articular cartilage. *Clin Orthop Relat Res*. 1975;(112):357-362.
25. Rokkanen PU, Bostman O, Hirvensalo E, et al. Bioabsorbable fixation in orthopaedic surgery and traumatology. *Biomaterials*. 2000;21(24): 2607-2613.
26. Seeley MA, Knesek M, Vanderhave KL. Osteochondral injury after acute patellar dislocation in children and adolescents. *J Pediatr Orthop*. 2013;33(5):511-518.
27. Sophia Fox AJ, Bedi A, Rodeo SA. The basic science of articular cartilage: structure, composition, and function. *Sports Health*. 2009; 1(6):461-468.
28. Steadman JR, Briggs KK, Matheny LM, et al. Outcomes following microfracture of full-thickness articular cartilage lesions of the knee in adolescent patients. *J Knee Surg*. 2015;28(2):145-150.
29. Tabaddor RR, Banffy MB, Andersen JS, et al. Fixation of juvenile osteochondritis dissecans lesions of the knee using poly 96L/4D-lactide copolymer bioabsorbable implants. *J Pediatr Orthop*. 2010; 30(1):14-20.
30. Tew S, Redman S, Kwan A, et al. Differences in repair responses between immature and mature cartilage. *Clin Orthop Relat Res*. 2001;(suppl 391):S142-S152.
31. Toupin JM, Lechevallier J. Osteochondral fractures of the external femoral condyle after traumatic patellar dislocation during physical exercise in children. *Rev Chir Orthop Reparatrice Appar Mot*. 1997; 83(6):540-550.
32. Tuompo P, Arvela V, Partio EK, et al. Osteochondritis dissecans of the knee fixed with biodegradable self-reinforced polyglycolide and polylactide rods in 24 patients. *Int Orthop*. 1997;21(6):355-360.
33. Vaquero J, Vidal C, Cubillo A. Intra-articular traumatic disorders of the knee in children and adolescents. *Clin Orthop Relat Res*. 2005;(432): 97-106.
34. Weckstrom M, Parviainen M, Kiuru MJ, et al. Comparison of bioabsorbable pins and nails in the fixation of adult osteochondritis dissecans fragments of the knee: an outcome of 30 knees. *Am J Sports Med*. 2007;35(9):1467-1476.