Successful Fixation of Traumatic Articular Cartilage–Only Fragments in the Juvenile and Adolescent Knee

A Case Series

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Background: Some surgeons are now considering fixation of traumatic chondral-only fragments in juvenile knees, but few data remain to guide treatment.

Purpose: To determine if surgical fixation of chondral-only fragments in the juvenile knee results in an adequate healing response with successful imaging and clinical outcomes.

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

Methods: Data were collected on 16 skeletally immature patients treated with fixation of chondral-only fragments with a minimum 1-year follow-up. Patients were selected by the operating surgeons based on the quality and size of the chondral fragment. Demographic data, lesion characteristics, surgical procedure details, complications, and postoperative imaging were assessed. Validated outcome measures were collected pre- and postoperatively and included the following scores: International Knee Documentation Committee (IKDC), Marx Activity Scale, Knee injury and Osteoarthritis Outcome Score (KOOS), Hospital for Special Surgery Pediatric Functional Activity–Brief Scale (HSS Pedi-FABS), Patient-Reported Outcomes Measurement Information System (PROMIS)–Physical Health and PROMIS–Psychological Health, and Tegner.

Results: The mean age of our patient cohort was 14.9 years. The mean size of the repaired defects measured 3.2 cm². Injury sites included the patella (n = 1), medial femoral condyle (n = 3), trochlea (n = 4), and lateral femoral condyle (n = 8). Within the mean follow-up time of 42.3 months (range, 15-145), there was 1 clinical failure with loosening of the chondral fragment and the need for reoperation. At a mean follow-up of 3.5 years, the mean (interquartile range) patient-reported outcome scores were as follows: IKDC, 95.2 (94.3-100); Marx Activity Scale, 11.5 (11.5-16); KOOS, 95.81 (93.5-95.81); HSS Pedi-FABS, 16.94 (11.5-26); PROMIS–Physical Health, 93.75% (90%-100%); PROMIS–Psychological Health, 90% (88.75%-100%); and Tegner, 5.69 (4.75-7). All patients who were engaged in sports before injury returned to the same or higher level of competition with the exception of 1 patient.

Conclusion: Primary repair of chondral-only injuries with internal fixation can be a successful treatment option in selected patients. Clinical and imaging results at final follow-up suggest that reintegration of the cartilage fragment is achievable and leads to excellent clinical function and a high return-to-sports rate.

Keywords: cartilage fragment; chondral injury; osteochondral defect; fixation; chondral-only fragment

Traumatic cartilage injuries typically occur in a pediatric and adolescent population and can result from episodes of patellar instability, forced hyperextension of the knee joint, or direct impact forces.25 The pediatric knee is more prone to pure chondral shear-off lesions because of the developing osteochondral unit, resulting in inferior mechanical properties of the interface between articular cartilage and subchondral bone.21 While osteochondritis dissecans fragments, consisting of visible subchondral bone and the overlying articular cartilage, have an incidence of approximately 0.03% in patients aged 10 to 20 years, full-thickness chondral fractures without visible bone are significantly less prevalent.28,37 Traumatic osteochondral fragments can be surgically reattached, yielding good to
excellent results.23 Given their intact layer of bony tissue on the undersurface, these fragments usually integrate well after refixation. Osteochondritis dissecans lesions, however, develop in most cases without a traumatic mechanism and are thought to be secondary to an impaired blood supply. They are usually associated with a lower healing rate after refixation.36 Management of chondral-only fragments, though, remains controversial: While the general treatment algorithm for clinical decision making regarding operative and nonoperative management is fairly well accepted, much room exists for interpretation on a case-by-case basis. Some previous studies have reported that articular cartilage without remaining bone has generally limited capacity to heal back to its subchondral bed.5,20,29,38 Chondral lesions with displaced or unstable fragments frequently demand surgical intervention, as they often cause clinical symptoms such as pain, locking, and catching and can initiate the first step of the cascade of joint degeneration, ultimately leading to joint damage and early-onset progressive cartilage deterioration if left untreated.1,3,34 Considering the potentially serious consequences of the injury, as well as the traditional dogma that fragments consisting of cartilage alone cannot integrate back successfully to their subchondral bone bed given the lack of healing potential, the physician is left with a dilemma when trying to communicate the best treatment options to the patient and family.5,40 It seems inappropriate to discard chondral fragments and subsequently choose restorative treatment options that often lead to formation of fibrocartilage or hyaline-like cartilage in the face of a significant cartilage lesion.32 These restorative options include debridement, marrow stimulation, osteochondral auto- or allograft transfer, cell-based regenerative techniques, particulated auto- or allograft articular cartilage, and cell-free scaffold implantation.16,30,32,39 While the best evidence for these procedures is mostly limited to the adult population, they have in common that they are not capable of producing a tissue replacement with the same mechanical and biological properties as the autochthonous articular cartilage.42 Given the lack of long-term data for these techniques in pediatric patients and the severity of degenerative joint disease after such injuries, the salvage of a large chondral fragment with successful primary fixation could be an ideal scenario, especially in the setting of young patients with open physes and high healing potential. Despite the ingrained notion that chondral fragments without attached subchondral bone lack blood supply and therefore have very limited healing potential, several cases have been published describing such surgical procedures.9,10,14,20,31,33,34,41 However, most studies have been limited by small sample sizes and short durations of follow-up as a result of the relative rarity of the condition.10,14 Considering the short-term risk of knee pain and disability and long-term progression to knee osteoarthritis, a better understanding of the outcomes of cartilage fixation in the pediatric knee is necessary.

The purpose of this study was to determine (1) the healing success rate, (2) patient-reported outcomes at final follow-up, and (3) return-to-sport rate after surgical fixation of chondral-only fragments in the juvenile knee. Our hypothesis was (1) that fixation of chondral fragments could be a successful and feasible path of treatment and (2) that long-term stability and healing of the fixated fragment could be achieved and therefore joint integrity could be preserved.

METHODS

Study Population and Design

This was a retrospective review of prospectively collected data from a single institution between 2009 and 2021 to determine if full-thickness, large, salvageable chondral fragments of the knee in a pediatric population could be successfully treated with open reduction and internal fixation of the fragment back to its bony bed. Institutional review board approval was obtained before the beginning of the study, and all study patients provided informed consent. A search of our institution’s medical database was performed to identify all pediatric patients who underwent surgery for chondral injuries of the knee during that period. Patients were included if they underwent primary internal fixation of a chondral-only fragment and presented with open physes at the time of surgery. Skeletal maturity was assessed with preoperative radiographs based on the status of the growth plate closure (open, partially open, closed). Only patients with chondral fragments with no visible and macroscopically detectable bone were included. Additional inclusion criteria were age <18 years at the time of surgery.
and documentation of previous traumatic knee injury felt to be the cause of the chondral injury. Exclusion criteria were closed physes, the inability to salvage a chondral fracture with internal fixation because of a small fragment size or fragmentation of the cartilage, and the presence of bone at the fragment. During the study period, no other cases with attempted cartilage repair of chondral injuries in the knee were performed on pediatric patients at the study institution. All attempted and performed repairs are reported in this study. A total of 16 patients were included.

**Surgical Technique**

Diagnostic arthroscopy was initially performed in all cases to assess for size, location, and condition of the chondral fragment. On the basis of this examination, each surgeon individually determined the need for conversion to parapatellar arthrotomy versus arthroscopy once it was determined that fixation of the chondral fragment would be performed. Open reduction and fixation were consequently carried out in all cases. The bone bed was prepared with curettage to remove hematoma, scar tissue, and fibrous and sclerotic tissue. Subsequently, bone marrow stimulation was carried out until bleeding bone was visible. Bone marrow stimulation was performed with a 0.045-inch K-wire to prevent the formation of wide holes, which alter and occasionally even inhibit the anchoring of chondral darts. If larger K-wires are used, chondral darts have a high probability of dislocating in the further course of healing. Most cases were performed with bioabsorbable implants. A detailed list of all utilized fixation methods is available in Table 1.

**Rehabilitation**

Postoperatively, patients remained at partial weightbearing, depending on injury location and surgeon preference, for a minimum of 6 weeks before advancing to full weightbearing. Physical therapy was described at the discretion of the operating surgeon. Weightbearing was consequently increased, and return to full activities and sports was permitted after achievement of full range of motion and strength.

**Outcome Measures**

All patients had standard 4-view radiographs at the time of the initial consultation, and magnetic resonance imaging (MRI) sequences were obtained preoperatively. MRI included, at a minimum, axial, coronal, and sagittal proton density–weighted and T2-weighted sequences with fat suppression. Healing was assessed with postoperative MRI when available; otherwise, the latest postoperative imaging modality was used (eg, radiograph, computed tomography). Radiographs, MRI, arthroscopic images, and surgical reports were reviewed by a fellowship-trained orthopaedic surgeon (M.H.) for presence of bone attached to the fragment. Failure was defined as any reoperation for the same cartilage lesion, such as repeat fixation, fragment excision, or a cartilage restoration procedure.

Postoperatively, all patients completed the following patient-reported outcome measures: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee injury and Osteoarthritis Outcome Score (KOOS), Patient-Reported Outcomes Measurement

**TABLE 1**

| Patient | Age, y | Sex | BMI | Fragment Size, cm² | Defect Location | Fixation Method | Concomitant Surgery |
|---------|--------|-----|-----|-------------------|----------------|----------------|-------------------|
| 1       | 12     | M   | 21.5| 2.8               | LFC            | 7 chondral darts | None              |
| 2       | 14     | F   | 31.8| 7.5               | Lateral trochlea | 2.5-mm headless compression screws + 2 chondral darts | None              |
| 3       | 14     | F   | 16.7| 1.5               | LFC            | 20-mm BioCompression screw + 4 chondral darts | MPFL reconstruction |
| 4       | 14     | M   | 17.2| 3.1               | MFC            | Two 20-mm BioCompression screws + 4 chondral darts | None              |
| 5       | 15     | M   | 25.3| 1.7               | LFC            | 3 chondral darts | Lateral retinacular release |
| 6       | 14     | M   | 24.2| 3                 | Patella        | 2.3-mm cannulated headless compression screws | MPFL reconstruction |
| 7       | 15     | M   | 18.6| 4.5               | MFC            | BioCompression screw + 6 darts | Partial meniscectomy |
| 8       | 16     | F   | 21.9| 1.2               | LFC            | 8 chondral darts | None              |
| 9       | 16     | M   | 28  | 5                 | MFC            | 3 chondral darts | Varus correcting osteotomy |
| 10      | 16     | M   | 33.3| 6                 | LFC            | 4 chondral darts | MPFL reconstruction |
| 11      | 16     | M   | 20.5| 2.5               | LFC            | 2 headless compression screws, 4 chondral darts | MPFL reconstruction |
| 12      | 16     | M   | 23.1| 1                 | Trochlea       | 2 PushLock anchors, fibrin glue | ACL reconstruction |
| 13      | 16     | M   | 26.6| 3.23              | Trochlea, lateral | 3 mini metal compression screws | None              |
| 14      | 14     | M   | 21.6| 3.75              | LFC            | 2.5-mm screw + 4 chondral darts | MPFL reconstruction |
| 15      | 13     | M   | 18.6| 3.78              | Trochlea       | 7 chondral darts | None              |
| 16      | 15     | M   | 30.7| 4                 | LFC            | 4 smart nails | MPFL reconstruction |

ACL, anterior cruciate ligament; BMI, body mass index; F, female; LFC, lateral femoral condyle; M, male; MFC, medial femoral condyle; MPFL, medial patellofemoral ligament.

All chondral darts were Arthrex bioabsorbable poly-L-lactide acid darts. The bioabsorbable compression screws were Arthrex 2.7-mm BioCompression screws.
Information System (PROMIS)—Physical Health and PROMIS—Psychological Health, Marx Activity Scale, Tegner Activity Scale, and the Hospital for Special Surgery Pediatric Functional Activity—Brief Scale (HSS Pedi-FABS).12 The return-to-sport rate was assessed during final follow-up, and the time between index surgery and return to sport was recorded.

Statistical Analysis

Statistics (mean, standard deviation, median, range, and frequencies) were analyzed for patient demographics (age, sex, body mass index, activity level), details of the chondral injury, imaging findings, operative reports, and postoperative outcome scores. All patient data were inputted and stored in Microsoft Excel (2010). Data analysis was performed using Microsoft Excel and SPSS (Version 28; IBM). The following were assessed: mechanism of injury, fragment features, and fixation technique, as well as postoperative clinical course, such as timing of sports clearance, healing on postoperative MRI, and any complications or reoperations. Descriptive statistics are reported as means 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 this is (1) a rare condition necessitating the use of all available patients and (2) a descriptive cohort study without direct statistical subgroup comparison.24

RESULTS

For the 16 study patients, the median age at the time of surgery was 14.9 years (IQR, 13.8-16.2), and the mean follow-up time was 42.3 months (IQR, 1.7-52.5), with a minimum 1-year follow-up. Twelve male and 4 female patients were treated. Fourteen patients had open physes and 2 had closing physes, while no adult patients with undetectable physes were included. All patients sustained a documented knee injury before surgery, directly associated with the onset of symptoms leading to initial clinical presentation. The characteristics of the study patients are summarized in Table 1.

Injury sites were the patella (n = 1), the medial femoral condyle (n = 3), the trochlea (n = 4), and the lateral femoral condyle (n = 8). The mean fragment surface was 3.15 cm² (IQR, 2.29-4.13) based on intraoperative measurements. All fragments were purely chondral. No bone was detectable on preoperative radiographs or MRI scans or in the operating room during preparation of the fragment. In all patients, the fragment was a single large piece. An open surgical approach (small arthrotomy) with preceding diagnostic arthroscopy was performed in all patients. Surgery was carried out at a mean 12 days (IQR, 7-25) after initial diagnosis.

A variety of stabilization methods were used to fixate the chondral fragment, such as headless bioabsorbable compression screws, bioabsorbable compression screws, chondral pins, and chondral darts. The lesion bed was prepared with gentle debridement and subchondral drilling until bleeding bone was visible to obtain bone marrow growth factors by breaking the subchondral calcified layer and facilitate ingrowth. Fixation implants were chondral darts alone (n = 6) (Figure 1), chondral darts and bioabsorbable headless compression screws (n = 6) (Figures 2 and 3), bioabsorbable headless compression screws alone (n = 1), absorbable suture with suture anchors (n = 1), bioabsorbable nails (n = 1), and metal compression screws (n = 1). In 6 of 16 cases, fibrin glue was utilized to additionally integrate the cartilage fragment. Bioabsorbable darts and screws were composed of polyactic acid, and absorbable suture was made of 6-0 braided polyactic acid. Six patients sustained a patellofemoral instability event and underwent concurrent medial patellofemoral ligament reconstruction. One patient sustained an anterior cruciate ligament tear, which was repaired concurrently (Table 1). In terms of trauma mechanism, 8 patients sustained a direct hit on the knee while falling to the ground playing sports (soccer, football, basketball, volleyball). Six patients cited a twisting motion of the knee with consecutive giving way. Two patients were lying on the ground while a football player fell on the extended knee.

The clinical success rate in our cohort was 93.75%. There were no major complications. A total of 2 reoperations were performed involving an arthroscopic evaluation. After the primary repair, 1 patient returned to surgery 6 months after the index operation for planned, uncomplicated hardware removal owing to the use of metallic headless mini compression screws for chondral fixation. At the time of hardware removal, the previously fixed chondral fragment was stable, ingrown to the surrounding cartilage, and resistant to probing. One patient presented with recurrent knee pain and catching symptoms and, 17 months after index surgery, had to be taken back to the operating room because of loosening of the previously fixed fragment. The patient’s 2.2-cm² fragment had been fixated with 3 chondral darts, and the loosened chondral fragment was not amenable to repeat reduction and fixation. Therefore, the fragments and chondral darts were removed, and microfracture was carried out with an awl in 4 locations within the lesion bed. One patient had hypertrophic scarring of the incision of the mini arthroscopy, which was addressed with plastic revision surgery 3 months after cartilage fixation. A third patient sustained delayed peroneal nerve compression from the postoperatively worn knee brace. The condition was fully resolved at 6-month follow-up, and full range of motion was present. Overall, 11 patients underwent postoperative MRI, and 1 patient underwent postoperative computed tomography at a mean 15.8 months (IQR, 5.7-23.1) after index surgery. Two patients had postoperative radiographs and 2 had no postoperative imaging. All but 1 of the images revealed evidence of complete healing of the chondral fragment back to the subchondral bone.

Postoperative outcomes are shown in Table 2. At the final follow-up, the mean (IQR) patient-reported outcome scores were as follows: IKDC, 95.2 (94.3-100); Marx Activity Scale, 11.5 (11.5-16); KOOS, 96.81 (93.5-95.81); HSS Pedi-FABS, 16.94 (11.5-26); PROMIS—Physical Health, 93.75% (90%-
100%; PROMIS–Psychological Health, 90% (88.75%-100%); and Tegner score, 5.69 (4.75-7).

Preoperatively, 14 patients had competed in ≥1 team sport, including football, soccer, baseball, basketball, track and field, and wrestling. Of the 14 patients, 13 (93%) returned to the same sports postoperatively and were competing at or above the preoperative level at final follow-up. The only patient with loosened cartilage fragment and the

Figure 1. Large full-thickness cartilage defect (16 × 16 mm) of the anterior aspect of the lateral femoral condyle with a displaced cartilage fragment within the anterior intercondylar fossa in a 12-year-old boy. (A) Sagittal T2-weighted magnetic resonance imaging obtained preoperatively. The arrow indicates the displaced fragment. (B) Intraoperatively visible lesion with intact subchondral bone. (C) Lesion bed after preparation. (D) The chondral fragment in situ. (E) The chondral fragment fixated with 6 chondral darts. (F) Fibrin glue was added to prevent synovial fluid ingress at the edges.

Figure 2. Large full-thickness displaced chondral fragment repaired back to the lateral trochlea with 2 bioabsorbable headless compression screws and 2 bioabsorbable chondral darts. (A) Loose fragment in magnetic resonance imaging. (B) Prepared lesion bed. (C) Fragment on back table. (D) Fragment fixated in situ.
need for revision initially returned to competitive basketball 10 months after index surgery and 6 months after revision surgery. The 1 patient who did not return to the same level of competitive sports had played baseball preoperatively; he focused on academics in his final years of high school, leaving no time for athletic engagements.

DISCUSSION

The treatment of articular cartilage injuries in pediatric patients remains challenging and complex, in part because of the scarcity of evidence to guide surgical management. While treatment algorithms for juvenile and adult osteochondral lesions have been established and a considerable amount of supportive data is available, the management of isolated chondral fragments without visible bone remains controversial. This study is the largest series of articular cartilage–only fragment fixation in a pediatric patient population. We have presented a high clinical success rate in conjunction with very good patient-reported outcomes and an excellent return-to-sports rate.

The juvenile population is at a higher risk of sustaining chondral-only injuries because the calcified cartilage layer

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**Figure 3.** Fixation of a large chondral fragment with 1 bioabsorbable compression screw and 4 bioabsorbable chondral pins in a 11-year-old girl. (A) Intraoperative lesion. (B) Fixed chondral fragment in situ. (C) Radiograph at 16-month follow-up. The arrow indicates the region of cartilage fixation.

**TABLE 2**

| Patient | Follow-up, mo | Radiographic Follow-up, mo | Returned to Sport | PROMIS–Physical, % | PROMIS–Psychological, % | HSS Pedi-FABS | KOOS | Marx | IKDC | Tegner |
|---------|---------------|---------------------------|------------------|--------------------|-------------------------|--------------|------|------|------|-------|
| 1       | 17            | 16                        | No               | 90                 | 100                     | 7            | 100  | 10   | 100  | 5     |
| 2       | 37            | 2                         | Yes              | 90                 | 75                      | 22           | 100  | 16   | 100  | 9     |
| 3       | 44            | 44                        | Yes              | 100                | 100                     | 28           | 100  | 16   | 100  | 8     |
| 4       | 20            | 12                        | Yes              | 100                | 100                     | 28           | 100  | 12   | 92   | 6     |
| 5       | 72            | 35                        | Yes              | 95                 | 95                      | 20           | 100  | 12   | 95.4 | 4     |
| 6       | 24            | 22                        | Yes              | 95                 | 85                      | 26           | 97   | 12   | 95.4 | 6     |
| 7       | 15            | 14                        | No               | 90                 | 90                      | 0            | 96   | 0    | 96.6 | 3     |
| 8       | 82            | 3                         | Yes              | 95                 | 95                      | 16           | 94   | 12   | 94.3 | 5     |
| 9       | 145           | 19                        | Yes              | 100                | 100                     | 18           | 92   | 13   | 96.6 | 7     |
| 10      | 21            | None                      | No                | 75                 | 50                      | 13           | 98   | 12   | 96.6 | 5     |
| 11      | 16            | 6                         | Yes              | 100                | 100                     | 20           | 98   | 16   | 95.4 | 7     |
| 12      | 14            | 14                        | No                | 100                | 100                     | 0            | 84   | 0    | 82.8 | 3     |
| 13      | 77            | 40                        | Yes              | 80                 | 50                      | 19           | 92   | 16   | 94.3 | 7     |
| 14      | 16            | 3                         | Yes              | 100                | 100                     | 28           | 100  | 16   | 100  | 7     |
| 15      | 42            | 24                        | Yes              | 100                | 100                     | 26           | 100  | 16   | 100  | 6     |
| 16      | 15            | None                      | No                | 90                 | 100                     | 0            | 82   | 0.00 | 84.20| 3     |

*Values presented as mean. HSS Pedi-FABS, Hospital for Special Surgery Pediatric Functional Activity–Brief Scale; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; PROMIS, Patient-Reported Outcomes Measurement Information System.*
(CCL) has not yet fully developed, leading to a weaker interface between articular cartilage and subchondral bone as compared with adults.\textsuperscript{25,34} The cause of these injuries is commonly attributed to a flexion-rotation mechanism of the knee that results in high shear stress between the patella and the lateral femoral condyle, being the most common location of injury, and the trochlear groove. The patellar impact results in a shear injury of the articular cartilage and potentially in the development of a loose body.\textsuperscript{26} Often, these injuries are concurrent with damage to the medial patellofemoral ligament, warranting cartilage and ligament repair as seen in 6 patients in this case series.\textsuperscript{25} Despite the elevated prevalence of patellar instability and patellar subluxation in the pediatric and adolescent population, the occurrence of salvageable, large, chondral-only fragments without a visible calcified matrix attached is rare.\textsuperscript{20,31} Given the rarity of the injury, little is documented regarding the long-term healing response of lesions managed with surgical fixation. The stability rate on imaging and the healing success rate in our study cohort at a mean 42.3 months of follow-up are reassuring and fall at or below estimates for skeletally immature study cohort at a mean 42.3 months of follow-up are reassuring rate on imaging and the healing success rate in our study cohort at a mean 42.3 months of follow-up are reassuring and fall at or below estimates for skeletally immature populations, with previously available studies trending toward similarly low rates of failure.\textsuperscript{10,14}

It has been a long-standing conviction that chondral fragments cannot be successfully repaired because of their lack of healing potential, stemming from the absence of visible subchondral bone at the undersurface of the fragment.\textsuperscript{6} However, microscopic bone may actually be present on the fragment, which results in healing and restoration of the articular cartilage surface. This is especially important in juvenile patients to prevent the development of posttraumatic arthritis.\textsuperscript{18} Surgical intervention employs a variety of fixation methods, such as bioabsorbable screws with or without a head, metal screws, bioabsorbable chondral darts, fibrin glue, and suture anchors.\textsuperscript{10,14} Studies of almost all these techniques have reported successful outcomes, despite the long-held belief that these fragments have healing capacity only if there is visible bone attached, allowing for bone-to-bone healing.\textsuperscript{26} Yet, the available data are usually published as single case reports with limited clinical implication.\textsuperscript{31,29} Anderson et al\textsuperscript{2} conducted a small study and presented promising results with fixation of chondral fractures. Our case series presents 16 patients with considerable follow-up time. To the best of our knowledge, this is the largest case series to validate the procedure of fixation of pure cartilage fragments in a juvenile population.

The current retrospective case series of 16 patients who underwent fixation of large chondral-only fragments in the knee with subsequent healing has demonstrated clinically near-normal patient-reported outcome scores at final follow-up. Moreover, just 1 patient had a postoperative complication affecting the repair site, and 93\% of patients returned to sports. In addition, the rate of MRI-confirmed healed lesions supports our hypothesis: that pure cartilage fractures can be successfully repaired in the juvenile knee.

Histological assessment was not performed in the present study. The scarcity of the tissue and the diameters of the fixed fragments allow for no separation of tissue for this purpose. While no bony attachments were visible during preparation and on preoperative radiographs and MRI scans, it cannot be ruled out that at least parts of the CCL were still attached to the fragment and would have been visible if histological assessment had been conducted. Nakamura et al\textsuperscript{33} reported a case of an injury in the deep zone in articular cartilage and integration of the chondral fragment with the subchondral bone after fixation of the chondral fragment. A postoperatively taken biopsy specimen showed a physiologically restored osteochondral junction after fixation. The authors hypothesized that growth factors and mesenchymal stem cells, recruited by bone marrow stimulation as part of the lesion bed preparation, facilitated the healing response. In addition, spindle-shaped cells were identified on the surface of the chondral fragment and suggested that the mesenchymal stem cells promoted tissue repair in bone marrow stroma by differentiating into chondrogenic and osteogenic cells to restore the osteochondral junction. We hypothesized that in cases of successful pure chondral fragment repair, parts of the CCL remain attached to the fragment, facilitating the healing response. The existence of microscopic amounts of bone in juvenile shear injuries may be sufficient to promote healing, as it has been shown that chondrocytes alone have poor intrinsic potential to heal to bone, regardless of maturation stage.\textsuperscript{40} Thus, we believe (1) that large chondral-only fragments without at least parts of the CCL are extremely rare because of a not-yet-demarcated osteochondral transition zone and (2) that the common chondral fracture without visible subchondral bone attached integrates well, especially in a juvenile patient population.\textsuperscript{4} Hevesi et al\textsuperscript{19} introduced a method for employing audible changes to achieve precise and optimal depth of chondral debridement, and we suggest that it can be used in the operating room to determine if the CCL is present on the chondral fragment. The group described a technique that allows for the use of volume- and pitch-based cues to optimize the level of debridement in joint preservation surgery, and it showed that the CCL can be identified by a specific audible pitch and volume while stroked with a curette. This technique offers an identification method of the CCL without the need for a histological specimen and further loss of scarce tissue.

While primary fragment fixation remains a subject of controversy, the patients in this case series showed excellent clinical and imaging results at final follow-up with just 1 revision for fragment loosening. Therefore, we postulate that fixation of salvageable chondral-only fragments of a size that allows for mechanical fixation may be a clinically effective means of preserving articular cartilage, especially in the juvenile, skeletally immature patient.

All but 1 implant used in this series were bioabsorbable and countersunk below the level of the articular surface. The prevalence of complications related to countersunk bioabsorbable implants in the fixation of osteochondritis dissecans fragments is currently the subject of controversy in the literature.\textsuperscript{3,17,22,27} In our study, 1 fragment was fixated with a metallic screw that necessitated planned hardware removal 6 months after index surgery. The use of biodegradable implants eliminates this second surgical procedure, which is associated with further comorbidities and potential damage of the opposing cartilage surface. While specific complications of bioabsorbable implants have been reported, such as bony lytic reactions and
inflammatory responses at the implant-bone interface, none of these have become apparent in the present case series. Among our study patients, 93.75% obtained clinical and imaging-based healing with both methods of fixation without complications associated with implants.

Limitations

Limitations to this case series are inherent to its small sample size and retrospective study design. Despite having a limited number of patients, to date, just 1 detailed case series, including only 10 patients, has emerged discussing fixation of pure chondral fragments in the knee. A recent multicenter investigation of osteochondral injuries in pediatric patients yielded 15 patients with a limited mean follow-up time of 12 months. The current study expands on the existing literature by reporting on a considerably sized case series with chondral-only fragment fixation with substantially longer follow-up and detailed patient-reported outcome parameters.

Another limitation of this study is that not all patients had undergone postoperative MRI to evaluate lesion healing. It is assumed, however, that patients with symptomatic knees would have sought medical attention, consequently leading to further imaging. None of the patients reported symptoms indicative of repair failure at final follow-up. An additional limitation is that no biopsies of the cartilage fragment were obtained for further histological examination. This procedure would have provided conclusive microscopic evidence to the presence of subchondral bone versus pure chondral fragments. The extraction of a biopsy is not feasible though, given the scarcity of tissue and the resulting mismatch of the fragment and the lesion bed. Additionally, a histological examination would prolong the intraoperative time considerably, potentially leading to increased infection rates and further comorbidities. Finally, although the mean follow-up in our study was 3.5 years, this may be too short to assess potential clinical failure of the repair procedure.

CONCLUSION

Data on the repair of chondral fractures remain scarce, but a growing body of case studies reports promising results of the procedure in a skeletally immature population. Despite the common paradigm that chondral fractures without visible bone have a poor healing outlook, the present study describes 16 cases of displaced chondral fractures with a successful healing rate of 93.75% after fixation with a mean follow-up of 3.5 years. Patients reported excellent clinical outcome scores and the return-to-sport rate was high. These results indicate that fixation of large, structurally intact chondral fragments may be a viable first-line treatment option for this rare injury type and thereby a pathway to perseverance of the native articular cartilage and joint homeostasis in young patients.

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