# Reliability of MRI Detection of Kaplan Fiber Injury in Pediatric and Adolescent Patients with ACL Tears

Brendan Y. Shi,*† MD, Benjamin Levine,‡ MD, Varand Ghazikhanian,‡ MD, Amador Bugarin,† MD, Grant Schroeder,† MD, Shannon Wu,† BS, Thomas Kremen,† MD, and Kristofer Jones,† MD

*Investigation performed at University of California, Los Angeles, Los Angeles, California, USA*

**Background:** While studies have described Kaplan fiber (KF) injury in up to 60% of adults with anterior cruciate ligament (ACL) tears, the incidence of KF injury in the pediatric and adolescent population remains unknown.

**Purpose:** To (1) determine the reliability of using magnetic resonance imaging (MRI) to identify KF injury in the pediatric and adolescent population and (2) define the incidence of KF injury in these patients with acute ACL injuries.

**Study Design:** Cohort study (diagnosis); Level of evidence, 3.

**Methods:** The authors retrospectively identified patients ≤18 years of age who underwent ACL reconstruction for acute tears between 2013 and 2020. All preoperative MRI scans were reviewed independently and in a blinded fashion by 2 musculoskeletal radiologists, who noted the presence of the KF complex and any evidence of injury; interrater reliability was assessed. Patient characteristics, time from injury to MRI, laterality, and concomitant ligamentous or meniscal injuries were recorded, and associations between patient or injury characteristics and KF integrity on MRI were assessed.

**Results:** In total, 51 patients (mean age, 14.9 years) met the inclusion criteria. Of these, 27 patients were female and 31 sustained an injury to the right knee. With respect to KF integrity, radiologist 1 visualized KF injury in 29% of patients, while radiologist 2 visualized KF injury in 35% of patients. In 12% of cases for radiologist 1 and 6% of cases for radiologist 2, KFs were unable to be visualized at all. The overall percentage agreement between the 2 radiologists was 76.5% with a kappa statistic of 0.57 (moderate agreement). There were no significant associations found between the presence of KF injury and patient age, sex, laterality, body mass index, concomitant ligamentous injury, or meniscal injury. However, visualization of KF injury on MRI was associated with a shorter time from index injury to MRI (15 days vs 23 days; $P = .044$) .

**Conclusion:** Approximately one-third of pediatric and adolescent patients who underwent ACL reconstruction were found to have KF injuries. Standard preoperative MRI scans can reliably be used to visualize KF injury in the majority of pediatric and adolescent patients with ACL tears, especially when the MRI is performed in the acute setting.

**Keywords:** kaplan fibers; anterior cruciate ligament; magnetic resonance imaging; pediatric; iliotibial band

Kaplan fibers (KFs), the deep connections between the iliotibial band (ITB) and distal femur, are key components of the anterolateral complex and contribute to anterolateral rotational stability of the knee[9,12] (Figure 1). Injuries to any of the 3 components of this complex (KFs, anterolateral ligament, and ITB) have been associated with high-grade pivot shift on examination and decreased rotational stability.[8,21,24] Biomechanical cadaveric studies have demonstrated that KFs approximate the ITB to the lateral epicondyle and cause ITB tightening with internal rotation.[6,16] This augments the ITB's ability to provide rotational stability to the knee, which, in the context of anterior cruciate ligament (ACL) reconstruction, has been shown to decrease the risk of graft failure.[7,22]

Magnetic resonance imaging (MRI) is commonly used to diagnose acute ligamentous knee injury including suspected ACL tears and related injuries. Studies have demonstrated that approximately 60% of pediatric patients with acute ACL tears have an additional knee injury on MRI.[27] However, no studies have specifically described the rate of associated extra-articular injuries in pediatric or adolescent patients with ACL tears, particularly with respect to the KF complex. Recently, Batty et al[3] demonstrated that KF integrity in adults can be reliably visualized and assessed on routine MRI. Marom et al[17] have reported on the proportion of concurrent ACL tear and KF injury in a combined pediatric and adult population. However, both the reliability of using MRI to visualize KF

The Orthopaedic Journal of Sports Medicine, 10(10), 23259671221128601
DOI: 10.1177/23259671221128601

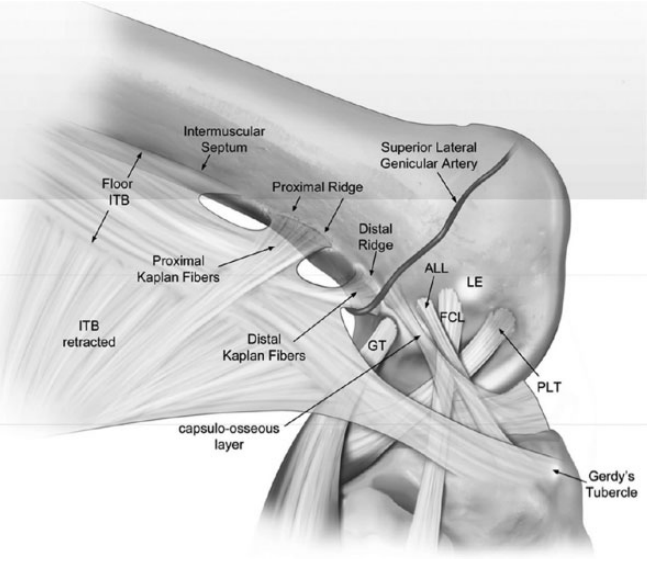


**Figure 1.** Illustration depicting normal anatomic relationship between Kaplan fibers and other anatomic landmarks. Image from Godin et al[9] (2017). Reprinted by permission of SAGE Publications. ALL, anterolateral ligament; FCL, fibular collateral ligament; GT, gastrocnemius tendon; ITB, iliotibial band; LE, lateral epicondyle; PLT, popliteus tendon.

injury in pediatric or adolescent patients and the incidence of KF injury in pediatric and adolescent patients with ACL tears remain unknown.

Pediatric and adolescent patients have been shown to be a distinct patient population compared with adults with respect to both failure rate and optimal ACL reconstruction technique. The rate of both ACL injury and ACL reconstruction is increasing rapidly in the pediatric and adolescent population,[30] and these patients continue to have an elevated risk of graft failure requiring revision surgery compared with their adult counterparts.[19,25,29] Understanding the proportion of KF injuries in these patients who have sustained an ACL tear may contribute to our understanding of this distinct patient population and potentially inform surgeons regarding who may benefit from extra-articular augmentation procedures.

The purpose of this study was to (1) determine the reliability of using MRI to identify KF injury in this high-risk population and (2) define the incidence of KF injury in pediatric and adolescent patients with acute ACL injuries. We hypothesized that the incidence of KF injury in this population would be higher than the historically reported KF injury rates in adult patients.

## METHODS

After institutional review board approval was obtained, all pediatric and adolescent patients who underwent ACL reconstruction between January 1, 2013, and December 30, 2020, at a tertiary care referral academic institution were identified. Inclusion criteria were (1) International Classification of Diseases, 9th Revision or 10th Revision diagnosis code for ACL injury, (2) Current Procedural Terminology (CPT) code 29888 for arthroscopic ACL reconstruction, (3) age $\leq$18 years, and (4) preoperative MRI scan of the injured knee available for review. Furthermore, to standardize imaging parameters, only patients who obtained their preoperative MRI scan at our institution were included. Patients with knee dislocations, ligament injuries, fractures, or any other concomitant knee injuries were not excluded from the study cohort. Patients provided informed consent to participate.

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) flowchart describing the patient inclusion process is shown in Figure 2. The initial record screening identified 228 records of patients $\leq$18 years of age with a diagnosis of ACL injury and a CPT code for ACL reconstruction. After chart review, 6 patients were excluded for incorrect coding (eg, surgery incorrectly coded as ACL reconstruction) and 131 patients were excluded because of missing preoperative MRI scans (eg, patient brought disk with MRI results to the consultation, but the images were not uploaded to our institution's picture archiving and communication system). Finally, 37 patients were excluded because their MRI scans were obtained at an outside institution. After excluding 3 duplicate records, 51 patients remained for final analysis.

Patient age, sex, body mass index (BMI), time from injury to MRI, and laterality of injury were collected from the electronic medical record. The presence of concomitant ligamentous or meniscal injuries was determined by reviewing operative notes and radiology reports. Patients with preoperative MRI findings of the collateral ligament or meniscal injury who did not have pathology noted during arthroscopy were not categorized as having concomitant injury.

*Address correspondence to Brendan Y. Shi, MD, UCLA Health Orthopaedic Surgery Center, 1225 15th Street, Suite 2100, Santa Monica, CA 90404, USA (email: byshi@mednet.ucla.edu).

†Department of Orthopaedic Surgery, University of California, Los Angeles, Los Angeles, California, USA.

‡Department of Diagnostic Radiology, University of California, Los Angeles, Los Angeles, California, USA.

Final revision submitted June 20, 2022; accepted August 2, 2022.

One or more of the authors has declared the following potential conflict of interest or source of funding: This study was funded in part by the H & H Lee Research Program at UCLA. B.L. has received consulting fees and honoraria from Canon Medical Systems USA. T.K. has received education payments from Micromed, consulting fees from Heron Therapeutics, honoraria from Fidia Pharma and Musculoskeletal Transplant Foundation, and hospitality payments from RTI Surgical. K.J. has received education payments from Arthrex and Micromed; consulting fees from Linvatec; nonconsulting fees from Arthrex; speaking fees from Linvatec; and honoraria from JRF Ortho, Musculoskeletal Transplant Foundation, and Vericel. AOSSM checks author disclosures against the Open Payments Database (OPD). 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 the University of California, Los Angeles (reference No. 21-000158).

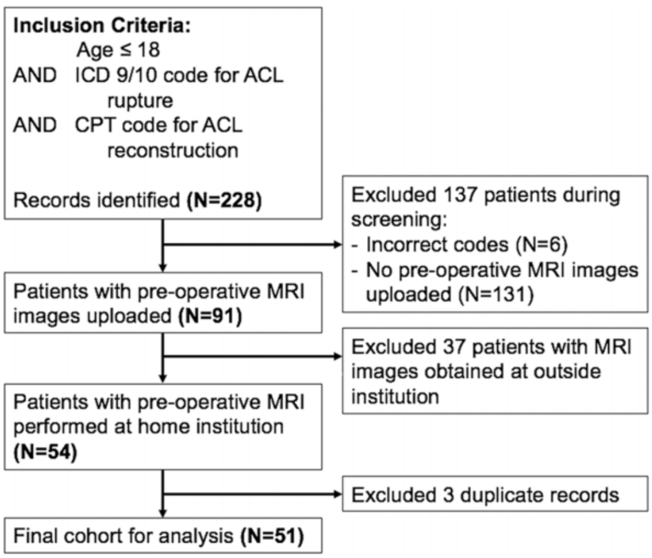


**Figure 2.** Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) flowchart of patient inclusion. ACL, anterior cruciate ligament; CPT, Current Procedural Terminology; ICD, International Classification of Diseases; MRI, magnetic resonance imaging.

TABLE 1
Kaplan Fiber Diagnostic Criteria

| Criterion | Definition |
|---|---|
| Visualized | Discrete fibrous band identified in ≥2 consecutive slices in 1 sequence |
| Intact | Homogeneous signal intensity and preserved contour |
| Injured | Heterogeneous signal intensity |
| | Partial or complete disruption of fiber contiguity |
| | Fluid signal within the fibrous bands |
| | Separation of fibers from attachments at the iliotibial band or distal femur |

All MRI scans were performed using a Siemens Magnetom Vida 3-T MRI scanner (Siemens AG) with a standard commercial knee coil. All MRI examinations were performed without contrast. Sequences were obtained per standard institutional protocols with parameters at or close to the following: repetition time, 2000 to 4700 milliseconds; echo time, 11 to 72 milliseconds; echo train length, 7 to 91; receiver bandwidth, 203 to 1180 Hz/Px; field of view, 140 to 330 mm; and slice thickness, 3 to 6 mm. Per standard institutional procedure, radiology technicians also modified parameters as necessary to obtain optimal visualization.

MRI scans were retrospectively reviewed independently and in a blinded fashion by 2 fellowship-trained musculoskeletal radiologists (B.L., V.G.) . Axial, coronal, and sagittal plane MRI scans were available for screening by each of the radiologists at their own discretion. They first focused on and reported the presence of ACL injury. Next, following the diagnostic criteria described by Marom et al[17] (Table 1), the radiologists characterized the KF bundles as visualized and intact, visualized and injured, or unable to be visualized. To meet criteria for visualization, a discrete fibrous band arising from the deep margin of the deep ITB and inserting on the distal femur must have been able to be identified on ≥2 consecutive slices in 1 plane. Criteria for KF injury included disruption or discontinuity of fiber contour, fluid signal within the fibrous bands, heterogeneous signal intensity, or separation of fibers from their attachments at the ITB or distal femur. Partial and complete tears were both recorded as injured. Criteria for intact KFs included homogeneous signal intensity and a preserved contour of the fibrous band between the distal ITB and distal femur. Consensus was defined as independent agreement on KF integrity between the 2 radiologists.

## Statistical Analysis

Patient characteristics were reported with means, standard deviations, and ranges. All collected variables were assessed for normality with the Shapiro-Wilk test. Associations between patient or injury characteristics and the presence of KF injury were assessed with Pearson chi-square test for categorical variables and the Mann-Whitney *U* test for nonparametric continuous variables. The overall percentage agreement between the 2 radiologists was calculated, and the kappa statistic was used to assess interrater reliability with the following scale: 0 to 0.2, slight; 0.21 to 0.4, fair; 0.41 to 0.6, moderate; 0.61 to 0.8, substantial; 0.81 to 1, almost perfect.[13] For comparative tests, a $P$ value <.05 was deemed statistically significant. Stata 12 (StataCorp LLC) was used for all analyses.

## RESULTS

In total, 51 patients with a mean age of 14.9 years (median, 15 years; SD, 2.1 years; range, 9-18 years) and mean BMI of 23.7 (SD, 5.3; range, 17.1-38.8) met our inclusion criteria and were included in this study. Of these, 27 patients (53%) were female and 31 (61%) sustained an injury to the right knee. Postinjury MRI was obtained an average of 24 days after injury (SD, 33 days; range, 0-182 days). Of the total, 40 patients (78%) were found to have a concomitant collateral ligament or meniscal injury. Overall, 22 patients (43%) sustained concomitant medial collateral ligament (MCL) injuries, 11 (22%) had a lateral collateral ligament (LCL) injury, 13 (25%) had medial meniscal tears, and 18 (35%) had lateral meniscal tears.

Upon review of the MRI scans, the 2 musculoskeletal radiologists first reported a few qualitative observations to the study team. First, they reported the highest success identifying KFs using axial T2 fat-suppressed images (Figure 3), with comparative difficulty following the fiber course when using sagittal or coronal images. The standard 3-mm slices were often too thick to reliably identify the fibers on sagittal or coronal images, precluding the radiologists' ability to identify discrete proximal and distal fibers. Second, while adult patients were not included in this study, the radiologists reported that compared with their

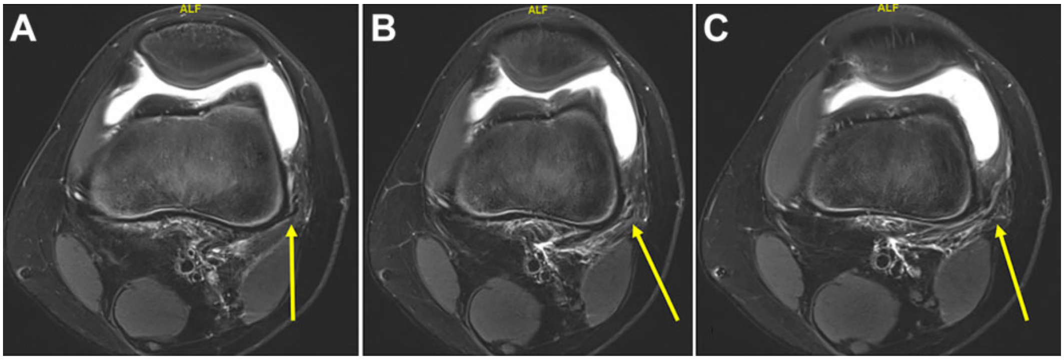


**Figure 3.** Uninjured Kaplan fibers. Series of consecutive axial T2 fat-suppressed images of the left knee in a pediatric patient with an anterior cruciate ligament injury with visualized, intact Kaplan fibers. (A) Arrow denotes insertion of Kaplan fibers onto the posterolateral distal femur. (B, C) Arrows denote Kaplan fibers joining with the lateral intermuscular septum and an iliotibial band.

TABLE 2
Kaplan Fiber Magnetic Resonance Imaging Findings[a]

| Finding | Radiologist 1 | Radiologist 2 |
|---|---|---|
| Not visualized | 6 (11.8) | 3 (5.9) |
| Visualized, uninjured | 30 (58.8) | 30 (58.8) |
| Visualized, injured | 15 (29.4) | 18 (35.3) |

[a]Data are reported as n (%).

experience reviewing MRI scans of adult knees, the KFs in our pediatric and adolescent patient cohort were noticeably smaller and thinner.

Between the radiologists, radiologist 1 (B.L.) noted ACL injury in 92% of patients, while radiologist 2 (V.G.) noted ACL injury in 94% of patients, with 94% agreement and a kappa statistic of 0.54 (moderate agreement). With respect to KF integrity, radiologist 1 noted KF injury in 29% of patients, while radiologist 2 noted KF injury in 35% of patients (Table 2, Figure 4). KFs were not discernible in 12% of cases for radiologist 1 and 6% of cases for radiologist 2. The overall percent agreement between the 2 radiologists for KF integrity was 76.5% with a kappa statistic of 0.57 (moderate agreement).

When limiting analysis to patients for whom the radiologists established consensus, there was a higher percentage of LCL injury in the KF-injured group compared with the KF-intact group (46% vs 16%; $P = .045$). Visualization of KF injury on MRI was associated with a shorter time from index injury to MRI (15 days vs 23 days; $P = .044$). With the numbers in this study, we could identify no statistically significant associations between the presence of a KF injury and patient age, sex, laterality, BMI, or the presence of an MCL or meniscal injury.

## DISCUSSION

In this study of 51 pediatric and adolescent patients with ACL injuries, KFs were able to be visualized on routine preoperative MRI scans in approximately 90% of all patients. A radiologic diagnosis of KF injury was made in 29% to 35% of all patients with moderate agreement noted between radiologists. Finally, a radiologic diagnosis of KF injury was associated with concomitant LCL injury as well as shorter delay between injury and MRI.

While there is a paucity of literature that focuses on pediatric and adolescent patients with ACL injury, recent studies have characterized the visualization rate and KF injury rate in adults. The findings vary significantly between studies, with Marom et al[17] reporting a 64% to 71% KF injury rate in a cohort of 72 patients with ACL tears and Batty et al[2] reporting only a 18.6% injury rate in a group of 161 patients with ACL tears. Using criteria similar to those used by Marom et al, we report a 29% to 35% KF injury rate. The magnitude of discrepancy between published studies highlights the importance of using consistent radiographic criteria for the diagnosis of KF injury. Marom et al deemed all KFs that had disruption of normal fiber contiguity, signal heterogeneity, or morphologic derangement on either coronal, sagittal, or axial MRI scans as injured. In contrast, Batty et al[3] enforced more stringent diagnostic criteria of KF injury, requiring 1 direct sign of injury or 2 indirect signs of injury. Direct signs included obvious fiber discontinuity or femoral avulsion, whereas indirect signs included thickening or signal change, bone marrow edema at the insertion site, soft tissue edema at the fiber region, or wavy appearance of the fibers. Using these more stringent diagnostic criteria likely decreased their sensitivity and led to a lower reported KF injury rate. Of the 23 KF injuries noted by Van Dyck et al[26] (of 69 patients with ACL tears), 21 were deemed grade 1, with "mild periligamentous edema with identifiable, continuous low-signal intensity fibers," and would not have been deemed injured by the criteria of Batty et al.[2] When applied to the more underdeveloped anatomy seen in pediatric and adolescent patients, we believe these stringent criteria would likely underestimate the true rate of KF injury.

Our study found a significant association between concomitant LCL injury and the presence of KF injury. While KFs and the anterolateral complex have been shown to resist internal rotation of the tibia relative to the femur, the LCL has a more significant role in controlling

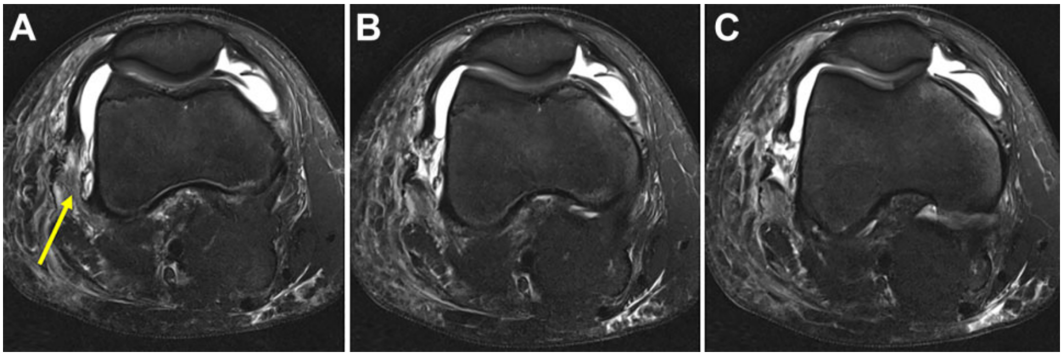


**Figure 4.** Injured Kaplan fibers. Series of consecutive axial T2 fat-suppressed images of the right knee in a pediatric patient with an anterior cruciate ligament injury with torn Kaplan fibers. (A) Arrow denotes a complete tear at Kaplan fiber insertion onto the posterolateral distal femur. (B, C) Disruption of Kaplan fiber attachments to the lateral intermuscular septum and iliotibial band.

external rotation forces.[10,11] While it may not be surprising that patients who sustained rotational forces significant enough to disrupt KFs are more likely to also present with concomitant collateral injury, there are many factors that play a role in ACL tears, and it is difficult to propose a relationship without more specifics regarding mechanism of injury. Batty et al[2] reported higher rates of MCL injury, lateral meniscal injury, and posteromedial tibial bone marrow edema in addition to LCL injury in patients with an ACL injury with KF tears, but we found no significant associations between the presence of KF injury and MCL or meniscal injury.[2] One possible explanation for this disparity is the biomechanical difference in the pediatric or adolescent knee compared with the adult knee. Not only have studies shown that younger patients have increased ligamentous strength relative to bone, decreasing their risk of concomitant ligamentous injury, but also the presence of the physis in skeletally immature patients contributes to increased flexibility at the knee joint.[20] This combined with the decreased stiffness of immature bone may allow the pediatric and adolescent knee to better absorb rotational stress.[20] Even within pediatric patients with ACL injury alone, Lee et al[14] reported that younger patients had a lower risk of concomitant ligamentous tears at the time of ACL injuries.

Although the rates of concomitant ligament tears for pediatric patients may be lower in the setting of ACL injuries, pediatric and adolescent patients undergoing ACL reconstruction have been shown to have significantly higher rates of retear compared with adults.[15] Wasserstein et al[28] analyzed more than 12,000 ACL reconstruction procedures and found that young age (15-19 years) was a significant independent risk factor for failure. Asai and colleagues[1] reported that 14.8% of skeletally immature patients required revision compared with 2.9% of adults. The explanation for this is likely multifactorial, including lower graft maturity rates, distinct intra-articular inflammatory environments, different autograft sizes and materials, and pediatric patients' overall high activity levels and relative difficulty adhering to postoperative restrictions.[1,5] Finally, as pediatric patients have been shown to demonstrate significantly greater amounts of internal tibial rotation both before and after ACL reconstruction,[4] increased rotational instability has been a commonly cited reason for higher failure rates. Asai et al[1] reported that more than 20% of skeletally immature patients had persistent pivot shift postoperatively compared with a 4% positive postoperative pivot-shift rate in adults. Given the role of KFs as a restraint against internal tibial rotation,[16] we expected a higher rate of KF injury in our cohort compared with the published literature on adult patients. Our observed rate of KF injury was far lower than the rate Marom et al[17] reported of 64% to 71%. Although it is possible that the aforementioned factors that allow skeletally immature knees to better absorb rotational stress (ligamentous laxity, open growth plates) may explain these results,[23] we did not find younger age to be associated with elevated rates of KF injury within our combined pediatric and adolescent patient cohort.

In an effort to augment rotational stability,[6] lateral extra-articular tenodesis (LET) has garnered significant interest as an adjunctive procedure. LET has been shown to reduce clinical failure and graft rupture rates in young (14-25 years of age) patients with ACL-deficient knees at high risk for reinjury.[7] While LET has a well-supported role in augmenting revision ACL reconstructions at high risk for failure,[18] there remains no consensus on the specific indications for LET in the setting of primary ACL surgery. Characteristics such as high-grade pivot shift, meniscal deficiency, high tibial slope, or involvement in high-risk activities such as cutting sports have been listed as possible indications for LET augmentation, but additional objective measures of rotational laxity are needed. Our study found that standard postoperative MRI scans can visualize the presence of KFs in more than 90% of pediatric and adolescent patients with an ACL injury and that musculoskeletal radiologists can diagnose KF injury with moderate agreement, demonstrating the feasibility of using MRI to diagnose KF injury and assist with surgical decision making. Further studies correlating radiologic findings with clinical outcomes and physical examination findings are needed in order to determine the clinical significance of an MRI diagnosis of KF injury.

## Limitations

Our study does have limitations. First, it is likely that our MRI acquisition parameters are not identical to those of other institutions. Second, given our finding that increased time between injury and MRI is associated with a lower rate of KF detection, the average MRI delay of 24 days may lead to an underestimation of the true rate of KF injuries in our patients. Third, while our radiologists followed previously published criteria for the recognition of KF injury using MRI, there is no consensus on diagnostic criteria for KF injury, much less in pediatric and adolescent patients. This heightens the difficulty of accurately comparing our findings with existing literature. Fourth, despite identifying more than 200 patients who met our inclusion criteria, the majority obtained their MRI scans at an outside institution and were excluded from analysis, limiting our sample size to 51 patients. Because of this, our study may be underpowered to detect associations between KF injury and specific patient characteristics. Fifth, the presence of edema-like marrow signal intensity (ELMSI) was not included on the image collection sheet used by the radiologists, preventing assessment of any relationship between ELMSI and KF injury. And finally, while this study is the first to define a rate of KF visualization and injury in pediatric and adolescent patients with ACL injuries, we did not record the status of the growth plate and hence cannot comment on any association between skeletal maturity and rate of KF injury. However, we did not find younger age to be significantly associated with the presence of KF injury in our cohort of pediatric and adolescent patients.

## CONCLUSION

Approximately one-third of pediatric and adolescent patients who underwent ACL reconstruction were found to have KF injuries. Standard preoperative MRI scans can reliably be used to visualize KF injury in the majority of pediatric and adolescent patients with ACL tears, especially when the MRI is performed in the acute setting.

## REFERENCES


1. Asai K, Nakase J, Shimozaki K, Yoshimizu R, Kimura M, Tsuchiya H. Skeletally immature patient showed lower graft maturity than skeletally mature patient after ACL reconstruction with a rounded rectangular femoral tunnel. *Sci Rep*. 2021;11(1):19968. doi:10.1038/s41598-021-99532-1
2. Batty LM, Murgier J, Feller JA, O'Sullivan R, Webster KE, Devitt BM. Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury. *Am J Sports Med*. 2020;48(9):2213-2220. doi:10.1177/0363546520931854
3. Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. The Kaplan fibers of the iliotibial band can be identified on routine knee magnetic resonance imaging. *Am J Sports Med*. 2019;47(12):2895-2903. doi:10.1177/0363546519868219
4. Christino MA, Vopat BG, Waryasz GR, Mayer A, Reinert SE, Shalvoy RM. Adolescent differences in knee stability following computer-assisted anterior cruciate ligament reconstruction. *Orthop Rev*. 2014;6(4):5653. doi:10.4081/or.2014.5653
5. DeFrancesco CJ, Storey EP, Flynn JM, Ganley TJ. Pediatric ACL reconstruction and return to the operating room: revision is less than half of the story. *J Pediatr Orthop*. 2019;39(10):516.
6. Geeslin AG, Moatshe G, Chahla J, et al. Anterolateral knee extra-articular stabilizers: a robotic study comparing anterolateral ligament reconstruction and modified Lemaire lateral extra-articular tenodesis. *Am J Sports Med*. 2018;46(3):607-616. doi:10.1177/0363546517745268
7. Getgood AMJ, Bryant DM, Litchfield R, et al. Lateral extra-articular tenodesis reduces failure of hamstring tendon autograft anterior cruciate ligament reconstruction: 2-year outcomes from the STABILITY study randomized clinical trial. *Am J Sports Med*. 2020;48(2):285-297. doi:10.1177/0363546519896333
8. Getgood A, Brown C, Lording T, et al. The anterolateral complex of the knee: results from the International ALC Consensus Group Meeting. *Knee Surg Sports Traumatol Arthrosc*. 2018;27(1):166-176. doi:10.1007/s00167-018-5072-6
9. Godin JA, Chahla J, Moatshe G, et al. A comprehensive reanalysis of the distal iliotibial band: quantitative anatomy, radiographic markers, and biomechanical properties. *Am J Sports Med*. 2017;45(11):2595-2603. doi:10.1177/0363546517707961
10. Gollehon D, Torzilli P, Warren R. The role of the posterolateral and cruciate ligaments in the stability of the human knee: a biomechanical study. *J Bone Joint Surg Am*. 1987;69(2):233-242. doi:10.2106/00004623-198769020-00010
11. Hassebrock J, Gulbrandsen M, Asprey W, Makovicka J, Chhabra A. Knee ligament anatomy and biomechanics. *Sports Med Arthrosc Rev*. 2020;28(3):80-86. doi:10.1097/JSA.0000000000000279
12. Kennedy M, LaPrade C, Geeslin A, LaPrade R. An overview of clinically relevant biomechanics of the anterolateral structures of the knee. *Tech Orthop*. 2018;33(4):213-218. doi:10.1097/BTO.0000000000000300
13. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174. doi:10.2307/2529310
14. Lee RJ, Margalit A, Nduaguba A, Gunderson MA, Ganley TJ. Risk factors for concomitant collateral ligament injuries in children and adolescents with anterior cruciate ligament tears. *Orthop J Sports Med*. 2018;6(11):2325967118810389.
15. Lemme NJ, Yang DS, Barrow B, O'Donnell R, Daniels AH, Cruz AI. Risk factors for failure after anterior cruciate ligament reconstruction in a pediatric population: a prediction algorithm. *Orthop J Sports Med*. 2021;9(3):2325967121991165.
16. Lutz C, Sonnery-Cottet B, Niglis L, Freychet B, Clavert P, Imbert P. Behavior of the anterolateral structures of the knee during internal rotation. *Orthop Traumatol Surg Res*. 2015;101(5):523-528. doi:10.1016/j.otsr.2015.04.007
17. Marom N, Greditzer HG, Roux M, et al. The incidence of Kaplan fiber injury associated with acute anterior cruciate ligament tear based on magnetic resonance imaging. *Am J Sports Med*. 2020;48(13):3194-3199. doi:10.1177/0363546520956302
18. Miller TK. The role of an extra-articular tenodesis in revision of anterior cruciate ligament reconstruction. *Clin Sports Med*. 2018;37(1):101-113. doi:10.1016/j.csm.2017.07.010
19. Salmon LJ, Heath E, Akrawi H, Roe JP, Linklater J, Pinczewski LA. 20-year outcomes of anterior cruciate ligament reconstruction with hamstring tendon autograft: the catastrophic effect of age and posterior tibial slope. *Am J Sports Med*. 2018;46(3):531-543. doi:10.1177/0363546517741497
20. Shanmugam C, Maffulli N. Sports injuries in children. *Br Med Bull*. 2008;86(1):33-57. doi:10.1093/bmb/ldn001
21. Sonnery-Cottet B, Daggett M, Fayard J, et al. Anterolateral ligament expert group consensus paper on the management of internal rotation and instability of the anterior cruciate ligament: deficient knee. *J Orthop Traumatol*. 2017;18(2):91-106. doi:10.1007/s10195-017-0449-8
22. Sonnery-Cottet B, Saithna A, Cavalier M, et al. Anterolateral ligament reconstruction is associated with significantly reduced ACL graft rupture rates at a minimum follow-up of 2 years: a prospective

comparative study of 502 patients from the SANTI Study Group. *Am J Sports Med*. 2017;45(7):1547-1557. doi:10.1177/0363546516686057
23. Tagesson S, Witvrouw E, Kvist J. Differences in knee joint stabilization between children and adults and between the sexes. *Am J Sports Med*. 2013;41(3):678-683. doi:10.1177/0363546512473252
24. Terry GC, Norwood LA, Hughston JC, Caldwell KM. How iliotibial tract injuries of the knee combine with acute anterior cruciate ligament tears to influence abnormal anterior tibial displacement. *Am J Sports Med*. 1993;21(1):55-60. doi:10.1177/036354659302100110
25. Thorolfsson B, Svantesson E, Snaebjornsson T, et al. Adolescents have twice the revision rate of young adults after ACL reconstruction with hamstring tendon autograft: a study from the Swedish National Knee Ligament Registry. *Orthop J Sports Med*. 2021;9(10):23259671211038893.
26. Van Dyck P, De Smet E, Roelant E, Parizel PM, Heusdens CHW. Assessment of anterolateral complex injuries by magnetic resonance imaging in patients with acute rupture of the anterior cruciate ligament. *Arthroscopy*. 2019;35(2):521-527. doi:10.1016/j.arthro.2018.08.032
27. Vavken P, Tepolt F, Kocher M. Concurrent meniscal and chondral injuries in pediatric and adolescent patients undergoing ACL reconstruction. *J Pediatr Orthop*. 2018;38(2):105-109. doi:10.1097/BPO.0000000000000777
28. Wasserstein D, Khoshbin A, Dwyer T, et al. Risk factors for recurrent anterior cruciate ligament reconstruction. *Am J Sports Med*. 2013;41(9):2099-2107. doi:10.1177/0363546513493580
29. Webster KE, Feller JA, Leigh WB, Richmond AK. Younger patients are at increased risk for graft rupture and contralateral injury after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2014;42(3):641-647. doi:10.1177/0363546513517540
30. Werner B, Yang S, Looney A, Gwathmey F. Trends in pediatric and adolescent anterior cruciate ligament injury and reconstruction. *J Pediatr Orthop*. 2016;36(5):447-452. doi:10.1097/BPO.0000000000000482