# The Locations of Anterior Cruciate Ligament Tears in Pediatric and Adolescent Patients: A Magnetic Resonance Study

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**Background:** Recently, a resurgence of interest has been noted in anterior cruciate ligament (ACL) preservation in pediatric and adolescent patients. Different tear types, defined by their tear location, require different preservation techniques: proximal and distal avulsion tears can be treated with arthroscopic primary repair, whereas primary repair with biological scaffold has been proposed for midsubstance tears. The goal of this study was to assess the distribution of different tear types in pediatric and adolescent patients, as these are currently unknown.
**Methods:** A retrospective search in an institutional radiographic database was performed for patients under 18.0 years undergoing knee magnetic resonance imaging (MRI) for ACL tears between June 2005 and June 2016. Patients with reports of chronic tears, partial tears, and multiligamentous injuries were excluded. Tear locations were graded using MRI as: proximal avulsion (distal remnant length >90% of total length; type I), proximal (75% to 90%; type II), midsubstance (25% to 75%; type III), distal (10% to 25%; type IV), and distal avulsion (<10%; type V).
**Results:** A total of 274 patients (59% girls; mean ± SD age, 15.1 ± 2.1 y; range, 6.9 to 18.0 y) were included. Frequency of type I tears was 15%, type II 23%, type III 52%, type IV 1%, and type V 8% (of which 7% had bony avulsion). Prevalence of tear types varied with age. At age 6 to 10 years, 93% were type V (bony) avulsion tears. At age 11 to 13 years, 32% were type I, 16% type II, 32% type III, and 16% type V. At age 14 to 17 years, type III tears were more common (57%) than type I (14%), type II (25%) and type V (2%) tears.
**Conclusions:** It was noted that the ACL was torn at different locations depending on the patients' age. These data provide more information on the potential application for ACL preservation in pediatric and adolescent patients. Future studies correlating these findings with arthroscopy are needed before using MRI for preoperative planning of ACL preservation surgery.
**Level of Evidence:** Diagnostic level III.

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G.S.D. is a paid consultant for Arthrex and received a research grant from Arthrex (Naples, FL). The remaining authors declare no conflicts of interest.
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DOI: 10.1097/BPO.0000000000001041

**Key Words:** anterior cruciate ligament, tear location, tear type, primary repair, preservation

(*J Pediatr Orthop* 2017;00:000–000)

The incidence of anterior cruciate ligament (ACL) injuries in the pediatric population has significantly increased,[1] which can be explained by increase in sports participation, greater clinical awareness and improved diagnostic imaging.[2–5] It is estimated that ACL injuries currently represents a third of all pediatric knee injuries.[1,4,6]

Historically, the first surgical treatment of ACL injuries consisted of primary repair,[7–9] and initial short-term outcomes were good.[10–15] However, longer-term follow-up studies showed a deterioration of outcomes in both the adult[16,17] and pediatric population.[18] In 1991, Sherman et al[19] performed an extensive subgroup analysis in an attempt to find an explanation for this deterioration. They categorized ACL tears into 4 tear types, and noted a trend towards better outcomes in patients with proximal avulsion (type I) tears when compared with midsubstance (type IV) tears. Subsequently, authors reported excellent outcomes of primary repair of type I tears in the adult[20] and pediatric population[21] at mid-term follow-up.[22] Despite these promising results, the treatment of open primary repair was abandoned, and ACL reconstruction became the common treatment for all patients.[14,15]

ACL reconstruction in the pediatric and adolescent population is a good and reliable treatment but also has limitations, such as: damage to the growth plate with subsequent growth disturbance,[23] high failure rates,[24–26] and inadequate prevention of osteoarthritis.[27–31] As a result, a recent resurgence of interest in ACL preservation surgery, and especially primary repair for proximal tears, has yielded excellent results in the adult population,[32–35] and more recently also in the pediatric and adolescent population.[5,36,37]

With this resurgence of interest in ACL preservation with its potential benefits for the pediatric and adolescent population, it is important to know the incidence of different tear locations, but this is currently unknown. Therefore, a magnetic resonance imaging (MRI) study was performed with the goal of (I) assessing the distribution of different tear locations in the pediatric and adolescent population, and (II) assessing the role of age, sex, and injury mechanism on this distribution.

# METHODS

## Patient Selection

After institutional review board approval was obtained, an electronic search in our institutional radiology system (PACS, Sectra Workstation IDS7, version 16.1, Linköping, Sweden) was performed for patients below 18.0 years of age undergoing knee MRI at our institution between June 3, 2005 and June 2, 2016. The radiologist reports were screened for the diagnosis of ACL tears, and a total of 434 patients were identified. Patients were excluded if radiology reports indicated nonacute tears, defined as >1 month delay between injury and MRI (n = 48), partial tears (n = 104), or multiligamentous injuries (n = 8).

## MRI Measurements

MRI was performed with a 1.5-T or 3.0-T superconducting magnet (GE Medical Systems; Milwaukee, WI) using a standardized protocol. MRI was performed using 2-dimensional fast-spin echo images acquired along 3 anatomic planes (sagittal, coronal, axial) (time of repetition/time of echo, 4000 to 6000/25 to 30 ms; echo train length, 8 to 16; bandwidth, 32 to 62.5 kHz over entire frequency range; acquisition matrix, 512×256-416; number of excitations, 1 to 2; field of view, 15 to 16 cm; slice thickness, 3.5 mm with no gap). An additional sagittal inversion recovery sequence was obtained (time of repetition/time of echo, 5000 to 8000/18; echo train length, 8 to 16; time of inversion, 150 to 180; bandwidth 32 to 62.5; 256×192, 1 or 2 number of excitations; field of view, 16 to 18 cm; slice thickness, 3.5 to 4.0 cm). Examinations were performed in the supine position with a pad under the knee supporting it in extension and slight external rotation. The quadriceps was relaxed and no anesthesia was used. The extremity was secured in a commercial extremity coil (8-channel knee coil; GE Healthcare; Little Chalfont, UK) to ensure a consistent extremity position for all patients.

The ACL tear location was assessed using sagittal, coronal, and axial planes. First, the ligament was viewed on the sagittal plane, and then followed from distal to proximal to assess the tear location. Coronal and axial planes were critically reviewed to confirm tear location. If a spiral tear pattern was noted, the middle of the spiral part was defined as the tear location. If the distal remnant was sagged in, an assessment was made for the original distal and proximal remnant lengths, and thus the original tear location. If needed, a digital ruler was used for the exact tear location.

## Classification System

All ACL tears were classified as one of the following tear types (Table 1): proximal avulsion tears (type I, Fig. 1), proximal tears (type II, Fig. 2), midsubstance tears (type III, Fig. 3), distal tears (type IV, Fig. 4), or distal avulsion tears (type V, Figs. 5, 6). Type I and type V tears were further classified as soft tissue (Fig. 5) or bony avulsion tears (Fig. 6), and distal bony avulsion tears were further graded according to the Meyers-McKeever classification modified by Zaricznyj.[38,39] In a previous study, this classification system has been shown to have substantial interobserver reliability (κ, 0.670), and substantial to nearly perfect intraobserver reliability (range, 0.741 to 0.934).[40]

**TABLE 1.** Tear Type Classification System

| Tear Types | Description | Tear Location* (%) | |
|---|---|---|---|
| Type I | Proximal avulsion | > 90 | Soft tissue or bony avulsion |
| Type II | Proximal | 75-90 | |
| Type III | Midsubstance | 25-75 | |
| Type IV | Distal | 10-25 | |
| Type V | Distal avulsion | < 10 | Soft tissue or bony avulsion |

*Tear location indicates the length of distal remnant as percentage of ligament length.

## Data Collection

A research fellow (JPL), experienced with the design and implementation of this classification system, graded all ACL tear locations. Additional collected data from the MRI intake info were sex, side, injury mechanism, date of birth, date of injury, and date of MRI, which were used to calculate age and delay from injury to MRI. Outcomes of tear location distributions were further stratified by age, sex, and injury mechanisms.

## Statistical Analysis

Statistical analysis was performed using SPSS version 21.0 (IBM Software; Armonk, NY). Incidence of tear locations was reported in percentages. $\chi^2$ tests were used to compare the incidence of different tear locations in different subgroups, and Fisher exact tests were used when the number in one of the cells was <5. A *P*-value of <0.05 was considered statistically significant.

# RESULTS

## Study Cohort

A total of 274 patients were included with a mean ± SD age of 15.1 ± 2.1 years (range, 6.9 to 18.0 y), 59% were girls, and injuries were evenly distributed by side. Mean ± SD delay from injury to MRI was 7 ± 7 days (range, 0 to 31 d). Most common sports injury mechanisms were soccer (31%), skiing (16%), football (12%), basketball (11%), lacrosse (10%), and other/unknown (20%).

## Distribution of Different Tear Types

Type I tears were seen in 15% (all soft tissue avulsion), type II in 23%, type III in 52%, type IV in 1%, and type V in 8% of patients (1% soft tissue avulsion and 7% bony avulsion) (Table 2). No patients with different tear locations of the anteromedial and posterolateral bundle were identified. Of all bony avulsion tear types (n = 21), 29% had type I, 43% type II, 14% type IIIA, 10% type IIIB, and 5% type IV Meyers-McKeever fractures.

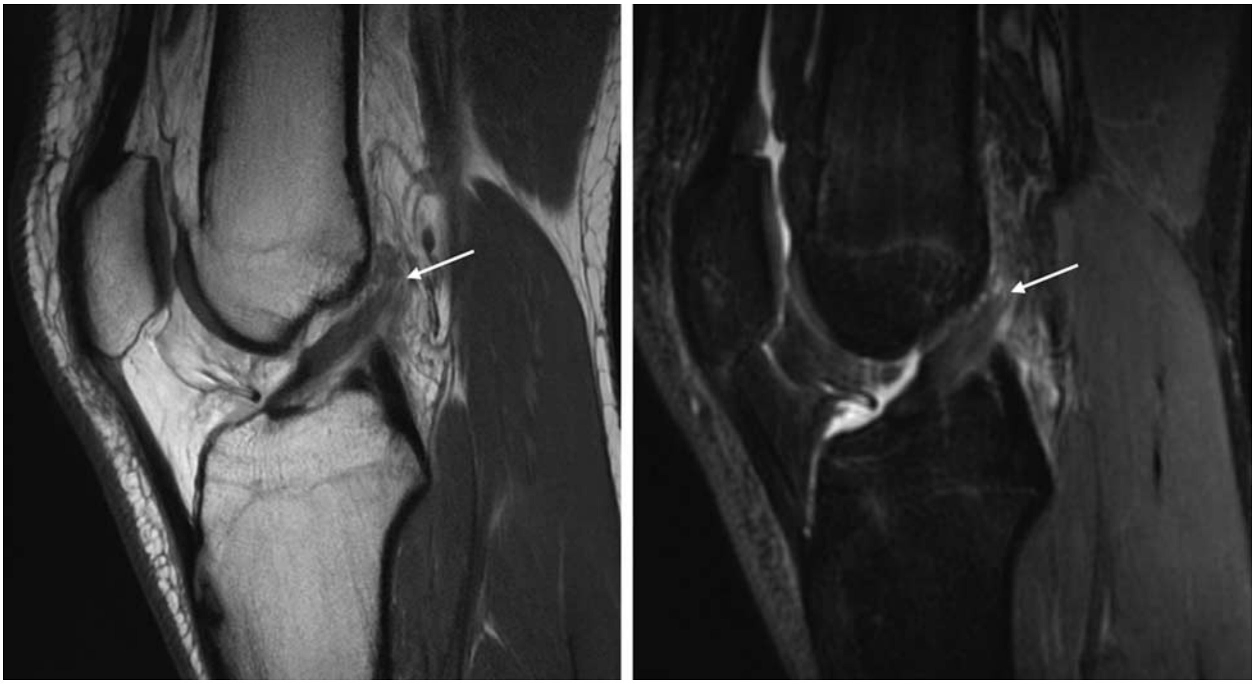

**FIGURE 1.** A type I tear (arrow) is shown on the sagittal T1 view (left) and on the sagittal T2 view (right).

Only 5% of patients were aged 6 to 10 years, 9% were 11 to 13 years, and the majority (85%) was 14 to 17 years of age. It was noted that in youngest patients, nearly all injuries were type V bony avulsion tears (93%). In patients aged 11 to 13 years, the different tear types were fairly even distributed between the tear types (Table 2). In patients aged 14 to 17 years, type III tears (57%) were more commonly seen than type I (14%) and type II tears (23%), whereas type V tears (2%) were rare (Table 2).

Comparing the tear locations by sex, it was noted that boys had a trend towards higher incidence of type I tears (20% vs. 12%; $P = 0.099$) and lower incidence of type III tears (46% vs. 57%; $P = 0.067$) than girls. No significant differences in tear distribution were noted

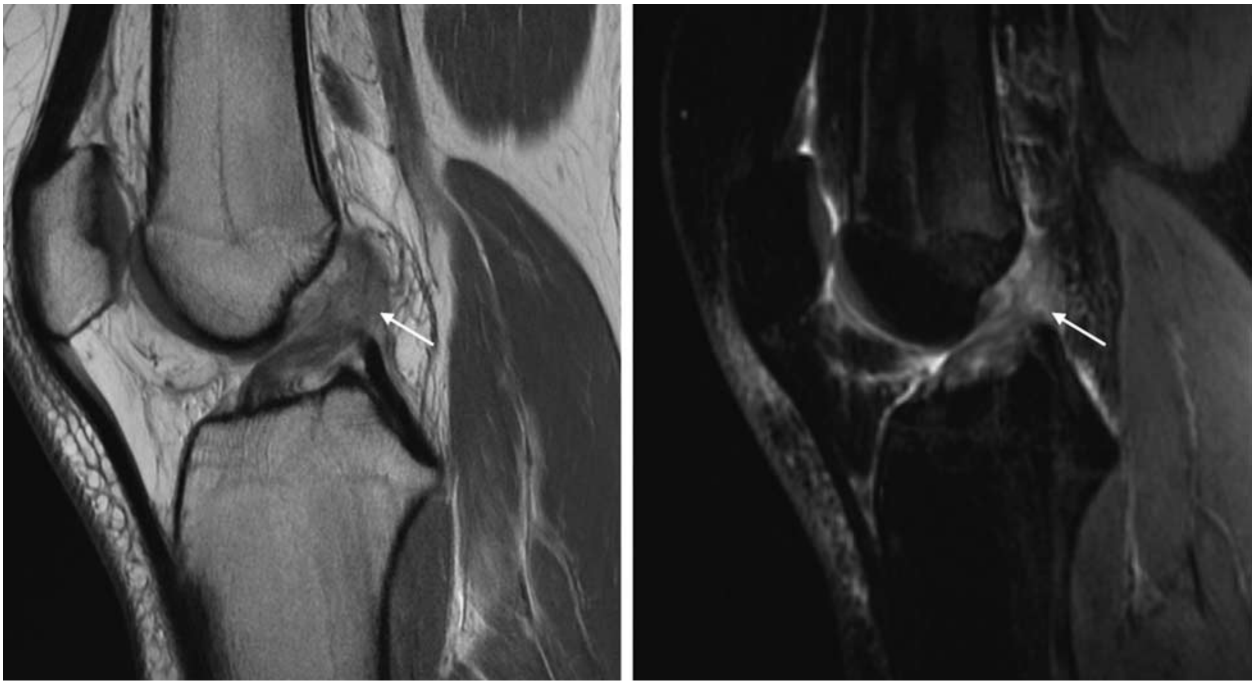

**FIGURE 2.** A type II tear (arrow) is shown on the sagittal T1 view (left) and on the sagittal T2 view (right).

**FIGURE 3.** A type III tear (arrow) is shown on the sagittal T1 view (left) and on the sagittal T2 view (right).

between boys and girls in the different age groups (Fig. 7).

Type I tears were less common in basketball injuries (7%) and skiing injuries (10%) when compared with the cohort average of type I tears (15%). Furthermore, a high incidence of type V tears was noted in skiing injuries (35%), but the average age in this group was lower than the average of the total cohort (13.2 vs. 15.1 y, respectively) (Table 3).

## DISCUSSION

Main finding of this study was that there was a large variation in the distribution of tear locations in the different

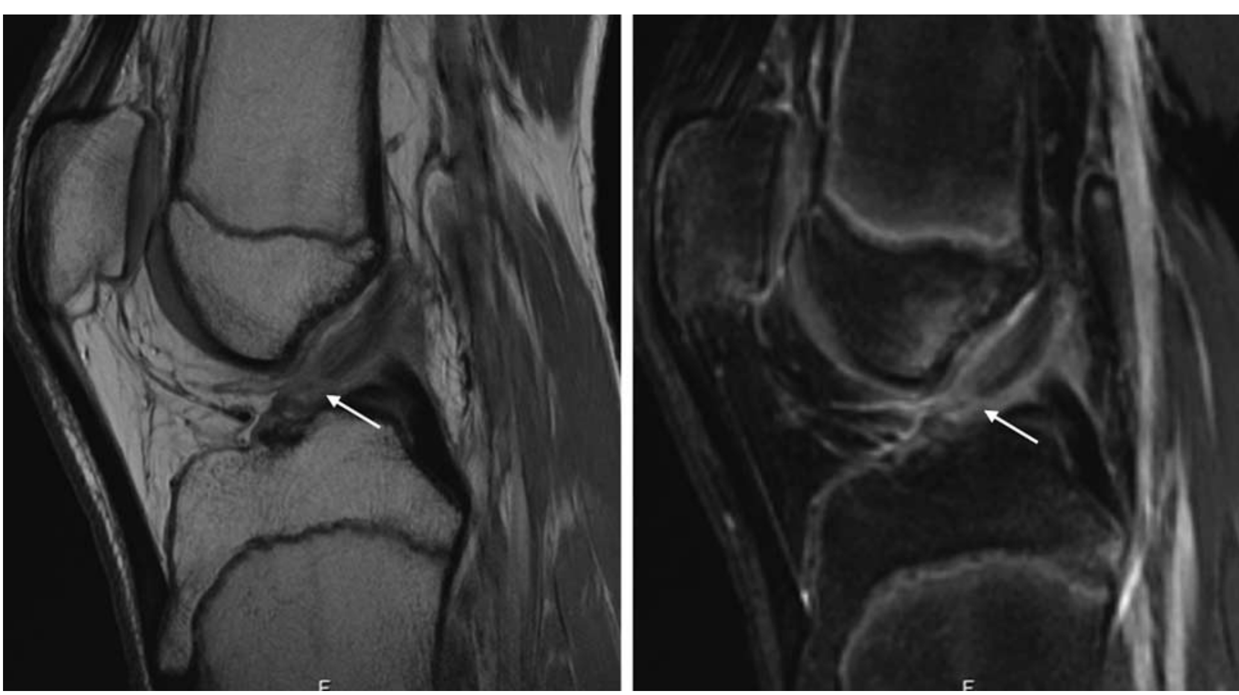

**FIGURE 4.** A type IV tear (arrow) is shown on the sagittal T1 view (left) and on the sagittal T2 view (right).

 

**FIGURE 5.** A type V soft tissue tear (arrow) is shown on the sagittal T1 view (left) and on the sagittal T2 view (right). On the left image, some distal remaining fibers (arrow) can be seen.

age groups. In the youngest patients, nearly all tears were distal bony avulsions, whereas in the patients aged 11 to 13 more tears were proximal or distal avulsion tears, and in the adolescent patients (age, 14 to 17) most tears were midsubstance. Sex and sports injury mechanism did not play an important role in tear location distributions in this cohort.

In this study, the overall incidence of type I tears was 15%. As we are aware of no other studies assessing the incidence of type I tears on MRI, these results could only be compared with clinical studies reporting the percentage of patients eligible for arthroscopic primary repair with type I tears.[33,35,36] Bigoni et al[36] found that

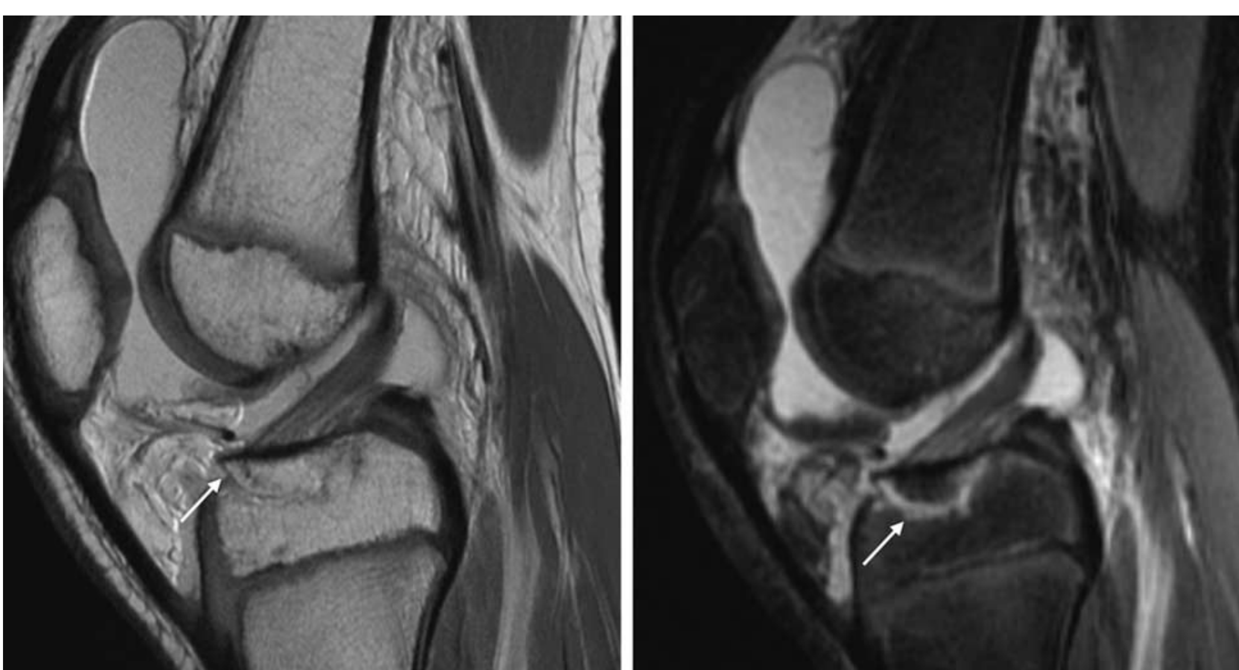

**FIGURE 6.** A type V bony avulsion (arrow) is shown on the sagittal T1 view (left) and on the sagittal T2 view (right).

**TABLE 2.** Incidence of Tear Types at Different Ages in Our Cohort

| | | (%) | | | | |
|---|---|---|---|---|---|---|
| **Age (y)*** | **Patients** | **Type I** | **Type II** | **Type III** | **Type IV** | **Type V** |
| 6 | 2 | 50 | 0 | 0 | 0 | 50 |
| 7 | 2 | 0 | 0 | 0 | 0 | 100 |
| 8 | 4 | 0 | 0 | 0 | 0 | 100 |
| 9 | 3 | 0 | 0 | 0 | 0 | 100 |
| 10 | 4 | 0 | 0 | 0 | 0 | 100 |
| 11 | 6 | 33 | 33 | 17 | 0 | 17 |
| 12 | 6 | 33 | 17 | 33 | 0 | 17 |
| 13 | 13 | 31 | 8 | 38 | 8 | 15 |
| 14 | 36 | 14 | 17 | 58 | 3 | 8 |
| 15 | 64 | 13 | 27 | 58 | 2 | 2 |
| 16 | 65 | 18 | 29 | 51 | 0 | 2 |
| 17 | 69 | 12 | 25 | 64 | 0 | 0 |
| 6-10 | 15 | 7 | 0 | 0 | 0 | 93 |
| 11-13 | 25 | 32 | 16 | 32 | 4 | 16 |
| 14-17 | 234 | 14 | 25 | 57 | 1 | 2 |
| Total | 274 | 15 | 23 | 52 | 1 | 8 |

*Age indicates the age of the patient at time of injury: 17 years indicates that the age of patients in this group ranges from 17.00 to 17.99.

6 of 46 (13%) of patients (age, 8 to 10 y) had complete type I tears on MRI, of which 5 were repairable (11%). It was not possible to compare these results with our findings because the number of ligamentous tears in this age group was too low. Two studies reported the incidence of adult patients eligible for primary repair (6% to 11%),[33,35] which is slightly lower than the incidence of type I tear in the adolescent group in this study (15%). This discrepancy may be explained by the fact that in these studies only included type I tears that were eligible for primary repair (ie, with sufficient tissue quality).

The classification system used in this study has been previously shown to have substantial interobserver (κ, 0.670), and substantial to nearly perfect intraobserver reliability (range, 0.741 to 0.934) when 3 observers (an orthopedic surgeon, radiologist, and a research fellow) graded the tear locations in 30 patients twice.[40] This classification was partially based on the tear locations as classified by Sherman et al,[19] and partially on the recently reported different ACL preservation techniques.[34,41,42] This study also reported tear-type distribution in 353 adult patients and noted that 16% had type I tears, 27% had type II tears, 52% had type III tears, and only 3% had bony avulsion tears.[40] Interestingly, these findings in adult patients correspond to the findings in patients aged 14 to 17 years in this study, indicating that adolescent patients have similar tear type distribution as adult patients.

The incidence of type V bony avulsions was high in the youngest group of patients aged 6 to 10 years (93%). Fehnel and Johnson estimated that 80% of the ACL injured patients younger than 12 years of age had tibial avulsion tears, which corresponds to our findings (15/21 patients, 71%). The high incidence of bony avulsions in this young population may be explained by the fact that the incompletely ossified tibial eminence fails earlier the ligament proper.[43] A recent systematic review showed that the mean age of children treated for bony avulsion fractures was 12.4 years,[43] which is higher than the average age of bony avulsions in our cohort (10.7 y of age). This difference might again be explained by the fact that this systematic review included only surgically treated patients, whereas it is likely that some patient in this study were ultimately treated conservatively given the high incidence of Meyers-McKeever types I and II.[44]

Data of this study may provide more information on eligibility for ACL preservation surgery, which is especially of interest in the pediatric and adolescent population. In this population, the current common treatment consists of ACL reconstruction, which has limitations. First of all, the risk of growth disturbance is higher with ACL reconstruction when compared with primary repair.[23] Secondly, recent studies showed high failure rates of ACL reconstruction in young patients (up to 28%).[24–26] Thirdly, ACL reconstruction does not prevent osteoarthritis at a later age with incidences varying between 15% and 48%, and even as high as 78% at 14 years postoperatively.[28–31] Interestingly, in a recent experimental porcine study, Murray and Fleming[45] found significantly less osteoarthritis following primary repair when compared with

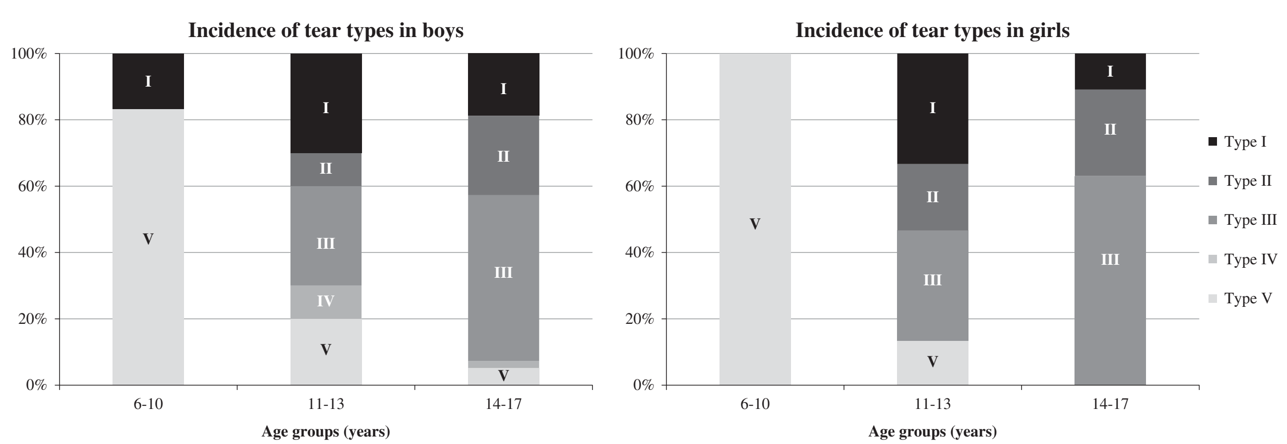


**FIGURE 7.** The incidence of the different tear types is seen in the different age groups for boys and girls.

**TABLE 3.** Incidence of Tear Types With the Different Injury Mechanisms (Sports) in Our Cohort

| | | | Incidence (%) | | | | |
|---|---|---|---|---|---|---|---|
| **Sports** | **Patients** | **Mean Age*** | **Type I** | **Type II** | **Type III** | **Type IV** | **Type V** |
| Soccer | 75 | 16.5 | 13 | 24 | 56 | 3 | 4 |
| Skiing | 40 | 13.1 | 10 | 8 | 45 | 3 | 35 |
| Football | 29 | 16.4 | 21 | 31 | 48 | 0 | 0 |
| Lacrosse | 27 | 16.3 | 17 | 33 | 46 | 0 | 4 |
| Basketball | 24 | 15.7 | 7 | 22 | 70 | 0 | 0 |

ACL reconstruction, concluding that primary repair may minimize the incidence of osteoarthritis. It is, however, currently unclear if posttraumatic osteoarthritis following ACL reconstruction is caused by the traumatic injury itself[46,47] or by the postoperative treatment in which the contact pressures and kinematics are altered compared with the native knee.[48–50]

Preservation of the ligament by primary repair can be especially of interest in pediatric and adolescent patients, as animal studies have shown that juvenile and adolescent animals have better healing capacity of the ACL than adult animals.[51–53] Recently, the first outcomes of arthroscopic primary repair of type I tears in pediatric patients have been reported in patients between 5 and 10 years of age with excellent outcomes and no growth disturbances.[5,36] Although the numbers in these studies are small, these studies have shown that the procedure is safe and that excellent outcomes can be achieved. The findings in this current study provide information about what percentage of patients might be eligible for preservation surgery, such as primary repair (type I), augmented repair (type II), repair with biological scaffold (type III), or other preservation techniques.[34,41,42] Further studies are necessary to correlate these MRI findings with the true eligibility for these preservation techniques at arthroscopy, in order that MRI can be used for preoperative planning of ACL preservation surgery. Furthermore, studies assessing the possibility of primary repair in patients with partial tears are necessary, as some studies have discussed a role for primary repair in proximal partial tears.[54,55]

Limitations were present in this study. First of all, the number of patients aged 6 to 13 years was limited, which can be explained by the fact that the incidence of complete ACL tears at this age is low. Secondly, it should be emphasized that no strong conclusions can be drawn on what percentage of patients can be treated with preservation surgery based on the data of this study, as tissue quality during arthroscopy plays an important role on the eligibility for successful preservation surgery.[33,34,36] Studies correlating these MRI findings with the eligibility for repair on arthroscopy are therefore needed. Thirdly, no data on Tanner stage or bone age was obtained as this data was retrieved from a radiologic database, and data was therefore only reported by age at injury. We have provided the data per age year and sex to provide data as complete as possible. Fourthly, overlap of injuries can occur (eg, type II or type III injuries for tears around proximal quarter), which could have influenced the incidence of tear types. In our experience, however, the number of cases with potential overlap was small. Finally, tear type distribution in this study may be dependent on the type of injury mechanisms present in our cohort and future larger studies are necessary to confirm our findings.

In conclusion, this study assessed the tear locations of ACL injuries in pediatric and adolescent patients using MRI. Different tear location distributions were present at different ages. The data suggest that there may be a greater potential application for the ACL preservation approach in these patient populations. Future studies correlating these findings with arthroscopy are needed to be able to predictably use MRI for preoperative planning of ACL preservation surgery.

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