Risk Factors for Failure After Anterior Cruciate Ligament Reconstruction in a Pediatric Population

A Prediction Algorithm

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Background: Anterior cruciate ligament reconstruction (ACLR) in pediatric patients is becoming increasingly common. There is growing yet limited literature on the risk factors for revision in this demographic.

Purpose: To (1) determine the rate of pediatric revision ACLR in a nationally representative sample, (2) ascertain the associated patient- and injury-specific risk factors for revision ACLR, and (3) examine the differences in the rate and risks of revision ACLR between pediatric and adult patients.

Study Design: Case-control study; Level of evidence, 3.

Methods: The PearlDiver patient record database was used to identify adult patients (age $\geq$20 years) and pediatric patients (age $<$20 years) who underwent primary ACLR between 2010 and 2015. At 5 years postoperatively, the risk of revision ACLR was compared between the adult and pediatric groups. ACLR to the contralateral side was also compared. Multivariate logistic regression was used to determine the significant risk factors for revision ACLR and the overall reoperation rates in pediatric and adult patients; from these risk factors, an algorithm was developed to predict the risk of revision ACLR in pediatric patients.

Results: Included were 2055 pediatric patients, 1778 adult patients aged 20 to 29 years, and 1646 adult patients aged 30 to 39 years who underwent ACLR. At 5 years postoperatively, pediatric patients faced a higher risk of revision surgery when compared with adults (18.0 % vs 9.2% [adults 20-29 years] and 7.1% [adults 30-39 years]; $P < .0001$), with significantly decreased survivorship of the index ACLR ($P < .0001$; log-rank test). Pediatric patients were also at higher risk of undergoing contralateral ACLR as compared with adults (5.8% vs 1.6% [adults 20-29 years] and 1.9% [adults 30-39 years]; $P < .0001$). Among the pediatric cohort, boys (odds ratio [OR], 0.78; 95% CI, 0.63-0.96; $P = .0204$) and patients $>$14 years old (OR, 0.62; 95% CI, 0.45-0.86; $P = .0035$) had a decreased risk of overall reoperation; patients undergoing concurrent meniscal repair (OR, 1.84; 95% CI, 1.43-2.38; $P < .0001$) or meniscectomy (OR, 2.20; 95% CI, 1.72-2.82; $P < .0001$) had an increased risk of revision surgery. According to the risk algorithm, the highest probability for revision ACLR was in girls $<$15 years old with concomitant meniscal and medial collateral ligament injury (36% risk of revision).

Conclusion: As compared with adults, pediatric patients had an increased likelihood of revision ACLR, contralateral ACLR, and meniscal reoperation within 5 years of an index ACLR. Families of pediatric patients—especially female patients, younger patients, and those with concomitant medial collateral ligament and meniscal injuries—should be counseled on such risks.

Keywords: knee; ligaments; ACL; pediatric sports medicine

The number of pediatric patients requiring anterior cruciate ligament (ACL) reconstruction (ACLR) has risen significantly over the past 20 years.[2,12] Some patients experience ACL graft rupture after primary reconstruction and require revision ACLR, which is associated with higher rates of complication as compared with primary reconstruction.[45] Previous studies have demonstrated multiple nonmodifiable risk factors for reoperation after primary ACLR, including younger age, female sex, preoperative ligamentous laxity, knee recurvatum, excess posterior tibial slope,

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and lower extremity coronal plane deformities.[10,21,24,26,30,34] Established modifiable risk factors include primary sport played, poor neuromuscular control of the lower extremity, abnormal movement patterns, decreased core strength, and premature return to sport.[10,21,33-35,40] In addition to revision ACLR, patients with a history of ACLR are at an increased risk for contralateral ACL tears.[21,44] Per findings by Kaeding et al,[21] pediatric patients may be at a higher risk of contralateral ACL tears than adult patients, as suggested by the odds of a contralateral tear after ACLR decreasing by 4% per year of increased age. However, when compared with the published outcomes after ACLR in adults, to date, there are limited large population-based studies examining pediatric ACL reoperation risk factors.

Comprehensive characterization of negative outcomes after primary ACLR in pediatric patients and an improved understanding of factors predisposing patients to reoperation can help providers identify at-risk individuals. The goals of this study were to examine the rates and risk factors for reoperation, revision ACLR, and contralateral ACLR after primary ACLR in pediatric versus adult patients. We also sought to develop a preliminary algorithm to predict the risk of revision after ACLR in pediatric patients, which upon validation can be used when counseling patients and their families on expected outcomes after surgery. We hypothesized that pediatric patients would have a higher risk of revision ACLR, as well as contralateral ACL tears, when compared with adult patients. Furthermore, we hypothesized that younger age and concomitant ligamentous and meniscal injuries would increase the risk of revision ACLR.

TABLE 1
Demographics of Pediatric and Adult Patient Cohorts Undergoing ACLR[a]

	Pediatric (n = 2055)	Adult 20-29 y (n = 1778)	Adult 30-39 y (n = 1646)
Age group, y			
<10[b]			
10-14	215 (10.4)		
15-19	1840 (89.1)		
20-24		958 (53.9)	
25-29		820 (46.1)	
30-34			785 (47.69)
35-39			861 (52.31)
Sex			
Female	1043 (50.8)	565 (31.8)	607 (36.9)
Male	1011 (49.2)	1212 (68.2)	1038 (63.1)
P value	.4910	**<.0001**	**<.0001**
Reoperations			
Combined ACLR and meniscus	191 (9.3)	101 (5.7)	76 (4.6)
ACLR only	203 (9.9)	59 (3.3)	51 (3.1)
Meniscus only	103 (5.0)	66 (3.7)	72 (4.4)
Contralateral ACLR	119 (5.8)	28 (1.6)	31 (1.9)

[a]Data are reported as No. (%). Bold indicates $P < .05$. Blank cells indicate no patients. ACLR, anterior cruciate ligament reconstruction.

[b]n < 11. For patient privacy, specific numbers are not reported.

METHODS

Data Source

The PearlDiver Patient Record Database (PearlDiver Inc) was utilized for this study. PearlDiver is a publicly available and Health Insurance Portability and Accountability Act–compliant national database, which includes inpatient and outpatient medical records of adult and pediatric patients drawn from Humana and United Healthcare claims as well as government claims from Medicare. Records within the database are composed of procedures defined by Current Procedural Terminology (CPT) codes and diagnoses defined by the International Classification of Diseases, Ninth and Tenth Revision, Clinical Modification (ICD-9-CM and ICD-10-CM). Individual patients within the database can be tracked through time. Laterality for procedures is identifiable through coded modifiers within the database.[3] Demographic characteristics of age and sex are also available for each patient. Private, Medicare, and Medicaid plans in the database were queried for 5 years between 2010 and 2015, capturing ~25 million records.

Patient Cohort

Patients who underwent ACLR were identified with first-instance CPT code 29888 (Appendix Table A1). Of these individuals, 3 cohorts of patients were defined by age category: pediatric patients (aged <20 years), adult patients aged 20 to 29 years, and adult patients aged 30 to 39 years (Table 1). As only an age range was coded in the database for each patient, pediatric patients were defined as individuals <20 years old, and those older were defined as adults. Distribution of male to female patients was obtained for the pediatric cohort and the 2 adult cohorts.

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Ethical approval was not sought for the present study.

Concomitant Meniscal Surgery and Revision Outcomes

Patients coded as undergoing concomitant meniscal surgery at the time of initial or revision ACLR, including either meniscal repair or meniscectomy, were defined by using the associated CPT codes (Appendix Table A1). For each cohort, patients requiring ipsilateral revision ACLR or contralateral ACLR were isolated using the appropriate CPT codes with laterality modifiers. Of patients requiring revision, those who underwent revision ACLR only, meniscal reoperation only, or combined ACLR and meniscal revision surgery were identified. Patients were identified as requiring a reoperation by a repeat instance of the ACLR CPT code for revision ACLR and a repeat or new instance of a meniscal surgery CPT code.

Risk Factors for Revision ACLR

A panel of candidate variables were considered as possible risk factors for reoperation (repeat meniscal surgery or revision ACLR) in pediatric patients (Appendix Table A1). These candidate variables were included as defined by ICD-9-CM and ICD-10-CM codes. Finally, an algorithm was developed to predict the risk of revision ACLR after pediatric ACLR.

Statistical Analysis

Descriptive statistics were generated as number and percentage of total, with time to revision reported as median and mean with standard deviation. Proportions were compared using the McNemar test. Risk of revision at 1 and 5 years was compared among the pediatric and adult cohorts using chi-square analysis. Time to revision ACLR was also examined for the pediatric and 2 adult cohorts by calculating the mean and median times for each cohort. Furthermore, for risk factor analysis, multivariate logistic regression was used to obtain an odds ratio (OR) for each candidate risk factor and to assess for significance.[21] The risk algorithm was developed using a multivariable logistic regression model with the risk factors found to be significant in the full multivariate analysis of all candidate predictors.[18] Regression model fit was estimated with the Hosmer-Lemeshow goodness-of-fit test. Statistical analysis was performed using the PearlDiver software, built on R Version 1.1.442 (RStudio Inc). A P value of .05 was set as the level of significance.

RESULTS

ACLR was performed in 2055 pediatric patients, 1778 adult patients aged 20 to 29 years, and 1646 adult patients aged 30 to 39 years (Table 1). In the pediatric cohort, 215 (10.4%) were between 10 and 14 years old, and 1840 (89.1%) were between 15 and 19 years old. Whereas pediatric ACLR was equally performed in female and male patients ($P = .4910$), the majority of adult patients aged 20 to 29 years (68.2%) and 30 to 39 years (63.1%) were male ($P < .0001$). More patients faced revision of the isolated ipsilateral ACL rather than the contralateral ACL after index surgery, in the pediatric cohort (9.3% vs 5.8%; $P < .0001$), adult cohort aged 20 to 29 years (3.3% vs 1.6%; $P < .0001$), and adult cohort aged 30 to 39 years (3.1% vs 1.9%; $P = .0077$).

TABLE 2
Concurrent Meniscal Surgery During Index ACLR and Risk of Revision Surgery[a]

	Pediatric	Adult 20-29 y	Adult 30-39 y
Concurrent meniscal surgery at index ACLR			
Meniscectomy	895 (43.3)	922 (51.9)	904 (54.9)
Meniscal repair	542 (26.2)	350 (19.7)	262 (15.9)
P value	**<.0001**	**<.0001**	**<.0001**
Revision after concurrent surgery			
Revision ACLR	203 (14.1)	96 (7.5)	67 (5.7)
Meniscal reoperation	223 (15.5)	131 (10.3)	109 (9.3)
P value	.3573	**.0240**	**.0020**

[a]Data are reported as No. (%). Bold indicates $P < .05$. ACLR, anterior cruciate ligament reconstruction.

Pediatric vs Adult ACLR Outcomes

Of ACLRs that involved concurrent meniscal surgery, meniscectomy was more frequently performed than meniscal repair across all age groups: pediatric patients (43.3% vs 26.2%; $P < .0001$), adult patients 20 to 29 years old (51.9% vs 19.7%; $P < .0001$), and adult patients 30 to 39 years old (54.9% vs 15.9%; $P < .0001$) (Table 2). In patients who had undergone ACLR and concomitant meniscal surgery, pediatric patients were equally likely to require revision ACLR or meniscal reoperation after the index procedure (14.1% vs 15.5%, respectively; $P = .3573$). As compared with adults, pediatric patients were also more likely to require revision ACLR and meniscal reoperation ($P < .0001$). Adults receiving concurrent meniscal surgery at the time of their index ACLR were more likely to receive meniscal reoperation than revision ACLR (20-29 years old, 10.3% vs 7.5% [$P = .0240$]; 30-39 years old, 9.3% vs 5.7% [$P = .0020$]).

For pediatric patients, 7.8% required revision ACLR at 1 year postoperatively, as compared with 6.1% of adults 20 to 29 years old and 4.6% of adults 30 to 39 years old ($P < .0001$) (Table 3). By 5 years postoperatively, pediatric patients continued to face the highest risk of revision ACLR at 18.0%, as opposed to 9.2% of adults 20 to 29 years old and 7.1% of adults 30 to 39 years old ($P < .0001$). The median time to revision decreased with increasing age. Patients 10 to 14 years old had a median time of 417 days to revision ACLR, whereas patients 30 to 39 years old had a median time of 258.5 days. Survivorship to revision of the index ACL procedure was significantly decreased in pediatric patients (log-rank test; $P < .0001$) (Figure 1).

Risk Factors for Reoperation

Among pediatric patients undergoing ACLR, 497 (21.2%) underwent a reoperation (revision ACLR or meniscal reoperation); specifically, 394 (19.2%) underwent revision ACLR during the study period (Table 1). Among adult

TABLE 3
Risk of Revision ACLR for Pediatric vs Adult Patients[a]

	Pediatric	Adult 20-29 y	Adult 30-39 y	*P* Value
Revision surgery, No. (%)				
1 y postoperative	160 (7.8)	108 (6.1)	76 (4.6)	<**.0001**
5 y postoperative	370 (18.0)	164 (9.2)	117 (7.1)	<**.0001**
Time to revision ACLR, d				
Median	417, 395[b]	365.5	258.5	
Mean ± SD	526.1 ± 444.0, 470.9 ± 362.7[b]	476.3 ± 503.1	579.0 ± 748.5	

[a]Bold indicates $P < .05$. ACLR, anterior cruciate ligament reconstruction.
[b]Data are presented by age group: 10-14 years and 15-19 years.

TABLE 4
Risk Factors for Revision ACLR in Pediatric Patients[a]

	Any Reoperation			Revision ACLR Only		
Risk Factor	OR	95% CI	*P* Value	OR	95% CI	*P* Value
Male sex	0.78	0.63-0.96	**.0204**	0.87	0.69-1.11	.2790
Age 15-19 y[b]	0.62	0.45-0.86	**.0035**	0.64	0.46-0.92	**.0148**
Meniscal injury	2.18	1.67-2.89	<**.0001**	2.28	1.66-3.21	<**.0001**
Repair	2.16	1.73-2.71	<**.0001**	1.84	1.43-2.38	<**.0001**
Meniscectomy	1.82	1.47-2.25	<**.0001**	2.20	1.72-2.82	<**.0001**
LCL injury	1.30	0.88-1.90	.1753	1.28	0.82-1.95	.2629
MCL Injury	1.73	1.37-2.17	<**.0001**	1.70	1.31-2.19	<**.0001**

[a]Bold indicates $P < .05$. ACLR, anterior cruciate ligament reconstruction; LCL, lateral collateral ligament; MCL, medial collateral ligament; OR, odds ratio.
[b]Reference: 10-14 years.

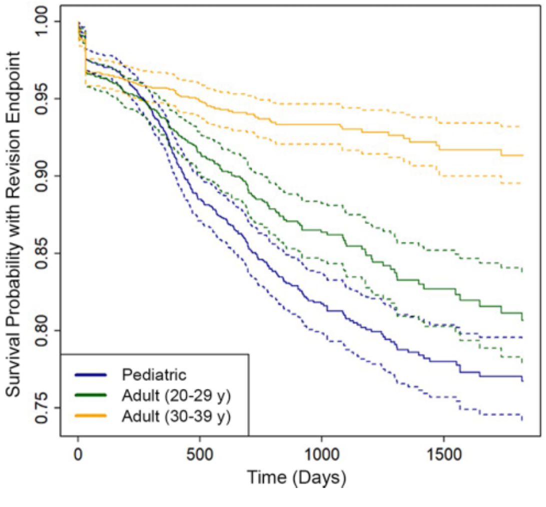

Figure 1. Kaplan-Meier survival analysis of pediatric vs adult ACLR with endpoint of revision ACLR. Dotted lines indicate 95% CI. ACLR, anterior cruciate ligament reconstruction.

patients, 425 (12.4%) underwent a reoperation, and 287 (8.4%) underwent revision ACLR.

For pediatric patients, boys were at decreased risk of reoperation (revision ACLR or meniscal reoperation; OR, 0.78; 95% CI, 0.63-0.96; $P = .0204$) (Table 4). When compared with patients aged 10 to 14 years, those who were aged 15 to 19 years were also at decreased risk of any reoperation (OR, 0.62; 95% CI, 0.45-0.86; $P = .0035$) and revision ACLR (OR, 0.64; 95% CI, 0.46-0.92; $P = .0148$). Meniscal injury was a risk factor for reoperation (OR, 2.18; 95% CI, 1.67-2.89; $P < .0001$) as well as revision ACLR specifically (OR, 2.28; 95% CI, 1.66-3.21; $P < .0001$). Concurrent meniscal repair or meniscectomy was an independent risk factor for any reoperation (repair: OR, 2.16; 95% CI, 1.73-2.71; $P < .0001$; meniscectomy: OR, 1.82; 95% CI, 1.47-2.25; $P < .0001$) as well as revision ACLR specifically (repair: OR, 1.84; 95% CI, 1.43-2.38; $P < .0001$; meniscectomy: OR, 2.20; 95% CI, 1.72-2.82; $P < .0001$). Medial collateral ligament (MCL) injury but not lateral collateral ligament injury was a risk factor for reoperation (OR, 1.73; 95% CI, 1.37-2.17; $P < .0001$) and revision ACLR (OR, 1.70; 95% CI, 1.31-2.19; $P < .0001$).

Algorithm for Probability of Pediatric Revision ACLR

An algorithm was constructed to determine the predicted probability of revision ACLR in pediatric patients based on 16 possible combinations ($2 \times 2 \times 2 \times 2$) of 4 dichotomous independent multivariate predictors (Table 5). The Hosmer-Lemeshow goodness-of-fit test revealed that the model had good fit to the data ($P = .7131$). In this model,

TABLE 5
Algorithm for Probability of Pediatric Revision ACLR Given Baseline Characteristics[a]

Multivariate Predictor				
Female Sex	Age 10-14 y	MCL Injury	Meniscal Injury	Probability of Revision ACLR, %
Yes	Yes	Yes	Yes	36.3
No	Yes	Yes	Yes	32.7
Yes	No	Yes	Yes	26.5
Yes	Yes	No	Yes	24.8
No	No	Yes	Yes	23.6
No	Yes	No	Yes	22.0
Yes	Yes	Yes	No	20.1
No	Yes	Yes	No	17.7
Yes	No	No	Yes	17.3
No	No	No	Yes	15.2
Yes	No	Yes	No	13.8
Yes	Yes	No	No	12.7
No	No	Yes	No	12.0
No	Yes	No	No	11.1
Yes	No	No	No	8.5
No	No	No	No	7.3

[a]ACLR, anterior cruciate ligament reconstruction; MCL, medial collateral ligament.

the highest risk for revision ACLR was observed in girls 10 to 14 years old with concomitant MCL injury and meniscal injury (36.3% risk of revision ACLR). However, a male patient >15 years old without MCL injury and without meniscal injury would be expected to have a 7.3% probability of revision ACLR.

DISCUSSION

ACL injury in the pediatric population is an increasingly common injury. As youth sports participation continues to increase, so has the incidence of ACL injuries and subsequent ACLR. Dodwell et al[12] demonstrated the incidence of ACLR in pediatric patients to have increased 190% between 1990 and 2009. Aside from increased sports participation and intensity of training in the pediatric population, the other likely causative factor leading to increased ACLR is the recent trend of early ACLR, as opposed to delayed (ie, until a patient reaches skeletal maturity), with the rationale being to prevent the potential ramifications of waiting, including irreparable meniscal tears and chondral lesions.[9,11,16,42,47] While there has been an abundance of literature regarding ACL injury prevention strategies and new ACLR techniques, research regarding risk factors for revision after ACLR in pediatric patients is limited. In the present study, we sought to determine the risk of pediatric ACLR requiring revision surgery and the associated patient- and injury-specific risk factors for such revision. We also sought to examine the differences in the rate and risks for revision between pediatric and adult patients. We subsequently used these data to develop an algorithm that potentially predicts the risk of revision ACLR and can help to counsel pediatric patients and their families before ACLR.

To our knowledge, the present study identifies the largest group of pediatric patients undergoing ACLR to date, which includes a cohort of 2055 pediatric patients. Within this group, there was a 7.9% rate of revision ACLR in the first year after the index surgery and an overall revision rate of 19.2% observed during the entirety of the study period, more than double the revision rate observed for their adult counterparts. Our data confirm those of previous studies in pediatric patients with revision rates that range from 4.5% to 30%.[2,5,8,12,17,36,43] The current study also demonstrated that children and adolescents have a higher risk of contralateral ACLR than do adults. An explanation for the increased revision rates in pediatric patients may be related to a relative increase in competitive sports participation, as well as the duration and frequency of such activities. This is supported by a study performed by Fabricant et al,[13,14] who measured activity levels using the Hospital for Special Surgery Pediatric Functional Activity Brief Scale, a pediatric-specific activity scale that takes into account the frequency and competitiveness of play. Specifically, those authors showed that activity levels decrease linearly as patients age. With regard to ACLR specifically, Barrett et al[1] demonstrated an increased revision rate in patients <25 years old versus those >25 years, with the younger cohort having a significantly higher Tegner activity level at the time of injury. Kaeding et al[21] also showed an increased risk of subsequent ACL injury in younger patients with higher Marx activity scores.

The mean time to revision ACLR in our pediatric/adolescent cohort was significantly later than that of adults, with the median time being 417 days for patients aged 10 to 14 years versus 258.5 days for those aged 30 to 39 years. This mirrors findings by other groups. Ho et al[17] and Webster et al[43] demonstrated revision ACLR in pediatric/adolescent patients to occur at a mean 13.6 and 18 months, respectively. Together, this suggests that pediatric patients may be at increased risk for revision for a prolonged period after their index surgery. The findings highlight a debate in the sports medicine community regarding when athletes should be allowed to return to play (RTP), attempting to balance early RTP with the risk of revision ACLR.[7,19,20] While there has been a trend for accelerated rehabilitation as introduced by Shelbourne and Nitz[39] to allow for rapid RTP (6-12 months), some data demonstrate that this may not be enough time for biologic recovery of the joint and graft "ligamentization," a period characterized by cell proliferation, revascularization, and reinnervation.[29] In addition to graft maturation, the literature has demonstrated persistent strength, proprioception, and neuromuscular deficits to be present up to 2 years after surgery.[28,37,38]

While the decision to RTP after an ACLR should be a joint decision-making process involving the athlete, parents, coaches, and involved athletic training staff, all parties should be aware of the risk of premature RTP. It may be prudent to encourage athletes who are earlier in their careers, which do not require rapid RTP, to delay their return to full activity as much as possible until they have maximized their rehabilitation and reinjury prevention potential. This is especially important for those patients who are younger and female and who have a concomitant MCL or meniscal injury, as shown in the algorithm presented in this study.

When looking at associated injuries and procedures at the time of ACLR, we demonstrated that concurrent meniscal or MCL injuries increase the risk of revision ACLR in the pediatric population. Additionally, for meniscal injuries, this risk was sustained despite the type of meniscal surgery performed (ie, meniscectomy or repair). For example, patients who underwent concurrent meniscal repair and meniscectomy were about 1.8 and 2.2 times more likely to require revision ACLR, respectively. Biomechanical studies support these findings, demonstrating increased in situ forces on ACL grafts and alteration of joint kinematics in meniscus-deficient knees.[25,31,32] While concurrent MCL injury is a known risk factor for revision surgery after ACLR, there is a scarcity of data on the effect of concurrent meniscal injury/surgery in pediatric patients.[41] In 2019, Cordasco et al[4] demonstrated no difference in the incidence of revision ACLR surgery in a cohort of patients <20 years old who had concomitant meniscal repair or meniscectomy. However, when patients enrolled in the Multicenter ACL Revision Study (MARS) cohort were examined, 74% undergoing revision surgery after ACLR had a current or previously treated meniscal injury,[46] although it is important to note that the mean age of this cohort was 26 years (range, 12-63 years). While a majority of the data regarding the synergistic relationship between the ACL and the menisci's role in maintaining knee stability are in adult patients, our data may demonstrate a similar finding for pediatric patients.

With any surgical intervention, it is important to understand the risk factors for revision, to minimize such risks, and to properly counsel patients and their families. In the present study, we noted the following independent risk factors for revision after ACLR in pediatric patients: female sex, age <15 years, concomitant meniscal injury, and concomitant MCL injury. Using methods similar to Kocher et al,[23] we created an algorithm to help predict the risk of ACLR in pediatric patients. Based on the described algorithm, patients at the highest risk for revision ACLR are female and <15 years of age with concomitant meniscal and MCL injuries, demonstrating a 36% risk of revision.

Such information can be valuable in managing patient expectations and should be considered when discussing RTP in patients at a high risk for revision. Unrealistic patient expectations preoperatively is well documented to negatively influence patient outcomes and satisfaction.[6,22,27] Feucht et al[15] found that highly active young patients with no history of knee surgery had the highest and most unrealistic expectations before ACLR. All patients in this study expected a normal or nearly normal knee joint after surgery, and 70% expected to return to sport at the same level without restrictions. Unrealistic or inflated expectations will inevitably lead to patient dissatisfaction. It is important to properly manage patient expectations during the entire course of care, to ensure that their expectations are realistic regarding postoperative function and the risk for revision after ACLR. The risk algorithm described in this study can be used for such counseling when discussing revision ACLR in pediatric patients.

This study is not without limitations. As with any database study, our data were dependent on accurate coding by providers and health care administrators. Furthermore, the database does not give information on the credentials or experience of the treating physicians, the type and source of graft used (autograft vs allograft, hamstring tendon, quadriceps tendon, bone–patellar tendon–bone, iliotibial band, etc), the technique used for reconstruction (physeal sparing, partial transphyseal, complete transphyseal, etc), or the rehabilitation protocols used by the treating providers, all of which are important factors related to revision ACLR. Comparison between pediatric patients and adult patients may have been limited, as reasons for undergoing revision likely differ between these age groups; however, the database did not capture these factors. There are also no data differentiating between medial and lateral meniscal injury/treatment nor any data regarding the specific method of meniscal repair. Also, given the lack of specific ICD-10-CM codes for multiligamentous knee injury, we were unable to exclude patients with such injuries. We were also unable to control for various patient-related factors that could alter the risk of revision, including activity level, sports participation, RTP time, anatomic risk factors (eg, tibial slope, ligamentous laxity, and mechanical alignment), and body mass index.

Given the limitations of the database resulting in the inability to include all of the aforementioned known risk factors for revision ACLR into the risk algorithm, in addition to the fact that it was established using only 1 data set, it should be emphasized that the risk algorithm proposed in this study must be validated on other retrospective or prospective cohorts to confirm its clinical usefulness. Despite these limitations, we were able to study the risk factors for revision ACLR in the largest pediatric cohort to date, including a nationally representative sample of patients from multiple institutions, as previous studies have been limited by their small sample sizes and patients from single institutions.[1,8,17,43] In light of this, we believe that the present study contributes important preliminary data for the development of a valid and unbiased risk assessment tool to predict reoperation after ACLR.

CONCLUSION

In this study, we identified a large cohort of pediatric patients undergoing ACLR over a 5-year period. Our data demonstrated an overall revision rate of 19.2% during the 5-year study period, with 7.8% of such patients undergoing revision ACLR within 1 year from their primary ACLR. The median time to revision ACLR in this population was 386 days. When compared with adults, pediatric patients are at significantly higher risk for revision ACLR and contralateral ACL injury. We also found that female sex, concomitant MCL injuries, and concomitant meniscal injuries significantly increased the risk of revision ACLR in the pediatric patient population. Finally, we developed a preliminary algorithm that upon validation can be individualized to patients based on their risk factors, allowing physicians to better counsel their patients regarding the risk of revision after ACL injury. This may allow patients and their families to align their expectations with the available data, and it might improve postoperative satisfaction.

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APPENDIX

TABLE A1
Codes Used for Risk Factors and Procedure Identification[a]

Procedure	CPT Code
ACL reconstruction	CPT-29888
Meniscal surgery	
Meniscal repair	CPT-29880, CPT-29881
Meniscectomy	CPT-29882, CPT-29883
Risk Factor	ICD Code
Meniscal injury	ICD-9-D-7170, ICD-9-D-7171, ICD-9-D-7172, ICD-9-D-7173, ICD-9-D-71740, ICD-9-D-71741, ICD-9-D-71742, ICD-9-D-71743, ICD-9-D-71749, ICD-9-D-7175, ICD-9-D-8360, ICD-9-D-8361, ICD-9-D-8362, ICD-10-D-M23200, ICD-10-D-M23201, ICD-10-D-M23202, ICD-10-D-M23203, ICD-10-D-M23204, ICD-10-D-M23205, ICD-10-D-M23206, ICD-10-D-M23207, ICD-10-D-M23209, ICD-10-D-M23211, ICD-10-D-M23212, ICD-10-D-M23219, ICD-10-D-M23221, ICD-10-D-M23222, ICD-10-D-M23229, ICD-10-D-M23231, ICD-10-D-M23232, ICD-10-D-M23239, ICD-10-D-M23241, ICD-10-D-M23242, ICD-10-D-M23249, ICD-10-D-M23251, ICD-10-D-M23252, ICD-10-D-M23259, ICD-10-D-M23261, ICD-10-D-M23262, ICD-10-D-M23269, ICD-10-D-M23300, ICD-10-D-M23301, ICD-10-D-M23302, ICD-10-D-M23303, ICD-10-D-M23304, ICD-10-D-M23305, ICD-10-D-M23306, ICD-10-D-M23307, ICD-10-D-M23309, ICD-10-D-M23311, ICD-10-D-M23312, ICD-10-D-M23319, ICD-10-D-M23321, ICD-10-D-M23322, ICD-10-D-M23329, ICD-10-D-M23331, ICD-10-D-M23332, ICD-10-D-M23339, ICD-10-D-M23341, ICD-10-D-M23342, ICD-10-D-M23349, ICD-10-D-M23351, ICD-10-D-M23352, ICD-10-D-M23359, ICD-10-D-M23361, ICD-10-D-M23362, ICD-10-D-M23369, ICD-10-D-Q686, ICD-10-D-S83200A, ICD-10-D-S83200D, ICD-10-D-S83200S, ICD-10-D-S83201A, ICD-10-D-S83201D, ICD-10-D-S83201S, ICD-10-D-S83202A, ICD-10-D-S83202D, ICD-10-D-S83202S, ICD-10-D-S83203A, ICD-10-D-S83203D, ICD-10-D-S83203S, ICD-10-D-S83204A, ICD-10-D-S83204D, ICD-10-D-S83204S, ICD-10-D-S83205A, ICD-10-D-S83205D, ICD-10-D-S83205S, ICD-10-D-S83206A, ICD-10-D-S83206D, ICD-10-D-S83206S, ICD-10-D-S83207A, ICD-10-D-S83207D, ICD-10-D-S83207S, ICD-10-D-S83209A, ICD-10-D-S83209D, ICD-10-D-S83209S, ICD-10-D-S83211A, ICD-10-D-S83211D, ICD-10-D-S83211S, ICD-10-D-S83212A, ICD-10-D-S83212D, ICD-10-D-S83212S, ICD-10-D-S83219A, ICD-10-D-S83219D, ICD-10-D-S83219S, ICD-10-D-S83221A, ICD-10-D-S83221D, ICD-10-D-S83221S, ICD-10-D-S83222A, ICD-10-D-S83222D, ICD-10-D-S83222S, ICD-10-D-S83229A, ICD-10-D-S83229D, ICD-10-D-S83229S, ICD-10-D-S83231A, ICD-10-D-S83231D, ICD-10-D-S83231S, ICD-10-D-S83232A, ICD-10-D-S83232D, ICD-10-D-S83232S, ICD-10-D-S83239A, ICD-10-D-S83239D, ICD-10-D-S83239S, ICD-10-D-S83241A, ICD-10-D-S83241D, ICD-10-D-S83241S, ICD-10-D-S83242A, ICD-10-D-S83242D, ICD-10-D-S83242S, ICD-10-D-S83249A, ICD-10-D-S83249D, ICD-10-D-S83249S, ICD-10-D-S83251A, ICD-10-D-S83251D, ICD-10-D-S83251S, ICD-10-D-S83252A, ICD-10-D-S83252D, ICD-10-D-S83252S, ICD-10-D-S83259A, ICD-10-D-S83259D, ICD-10-D-S83259S, ICD-10-D-S83261A, ICD-10-D-S83261D, ICD-10-D-S83261S, ICD-10-D-S83262A, ICD-10-D-S83262D, ICD-10-D-S83262S, ICD-10-D-S83269A, ICD-10-D-

(continued)

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Procedure	CPT Code
	S83269D, ICD-10-D-S83269S, ICD-10-D-S83271A, ICD-10-D-S83271D, ICD-10-D-S83271S, ICD-10-D-S83272A, ICD-10-D-S83272D, ICD-10-D-S83272S, ICD-10-D-S83279A, ICD-10-D-S83279D, ICD-10-D-S83281A, ICD-10-D-S83281D, ICD-10-D-S83281S, ICD-10-D-S83282A, ICD-10-D-S83282D, ICD-10-D-S83282S, ICD-10-D-S83289A, ICD-10-D-S83289D, ICD-10-D-S83289S
LCL injury	ICD-9-D-8440, ICD-10-D-M23641, ICD-10-D-M23642, ICD-10-D-S83421A, ICD-10-D-S83421D, ICD-10-D-S83421S, ICD-10-D-S83422A, ICD-10-D-S83422D, ICD-10-D-S83422S, ICD-10-D-S83429A, ICD-10-D-S83429D, ICD-10-D-S83429S
MCL injury	ICD-9-D-8441, ICD-10-D-S83411A, ICD-10-D-S83411D, ICD-10-D-S83411S, ICD-10-D-S83412A, ICD-10-D-S83412D, ICD-10-D-S83412S, ICD-10-D-S83419A, ICD-10-D-S83419D, ICD-10-D-S83419S

[a]ACL, anterior cruciate ligament; CPT, Current Procedural Terminology; ICD, International Classification of Diseases; LCL, lateral collateral ligament; MCL, medial collateral ligament.