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Factors Predictive of Concomitant Injuries Among Children and Adolescents Undergoing Anterior Cruciate Ligament Surgery

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Background: The timing of treatment for pediatric anterior cruciate ligament (ACL) injuries remains controversial. The risks of delaying reconstruction and the differences between age groups are poorly defined.

Purpose: To investigate factors that contribute to the prevalence and severity of concomitant chondral and meniscal injuries among patients aged 14 to 19 years versus those aged ≤14 years at the time of ACL reconstruction. The hypothesis was that concomitant injuries would be more prevalent in older versus younger subjects. Also, a delay in surgery would be predictive of the presence and severity of concomitant knee injuries requiring additional operative procedures.

Study Methods: Cohort study; Level of evidence, 3.

Methods: All subjects who underwent primary ACL reconstruction at a single tertiary pediatric hospital between 2005 and 2012 were retrospectively reviewed. The location, severity, and treatment of all concomitant knee injuries were recorded. Chi-square tests were used to compare the prevalence of chondral and meniscal injuries in the older (age, 14-19 years; n = 165) versus younger (age, ≤14 years; n = 66) cohorts. A multivariable logistic regression analysis was used to identify factors related to the presence of a concomitant injury that required additional treatment. Kaplan-Meier analyses were used to explore the relation between time to surgery and meniscal injury severity.

Results: There was a significant relationship between time to surgery and the development of an irreparable meniscal injury ($P <$ .05 for all) in both the younger and older groups. Time to surgery correlated with severity of chondral injury in the younger cohort (P = .0343) but not in the older cohort (P = .8877). In the younger cohort, only a delay in surgery >3 months (odds ratio [OR] = 4.8; 95% CI, 1.7-14.4; P = .0027) was significantly predictive of the presence of an injury that required additional operative procedures. In the older patients, a return to activity before surgery (OR = 3.8; 95% CI, 1.52-11.9; P = .0034) and obesity (OR = 2.5; 95% CI, 1.1-7.4; P = .0381) were significantly predictive of an injury that required additional operative procedures.

Conclusion: Compared with younger subjects, the prevalence of concomitant knee injuries as well as the need for additional operative procedures was greater among older subjects. A delay to surgery correlated with increased severity of injury among both older and younger populations. A delay in surgery >3 months was the strongest predictor of the development of a concomitant injury in the younger cohort. A return to activity and obesity were significantly related to the presence of a concomitant knee injury in the older cohort.

Keywords: delay in surgery; pediatric ACL; concomitant knee injuries; meniscus and chondral injuries

The pediatric anterior cruciate ligament (ACL) injury was historically believed to be a rare occurrence. There has been a paradigm change in the recognition and treatment of these injuries, as they are being diagnosed with increasing frequency in the younger and increasingly competitive athletic populations. The change in management is influenced by the development of surgical reconstructive techniques tailored for skeletally immature patients, evidence that limited physeal violation can be tolerated with a mitigated risk of growth arrest, and reports that nonoperative techniques are associated with unacceptable treatment outcomes.[1,12,16,25,28] Furthermore, level of play, level of competition, and intensity of training for the pediatric athlete have become progressively more demanding. These requirements may preclude activity modification as a treatment option.

Recent studies demonstrate that a delay to ACL reconstruction in patients younger than 14 years old is associated with inferior outcomes.[22,27] A delay in surgery has been shown to be associated with a significant increase

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in the prevalence of concomitant intra-articular injury as well as a decrease in knee stability.[22,27] Lawrence et al[22] reviewed 70 patients younger than 14 years who had ACL reconstruction and found that patient-reported knee instability and waiting longer than 12 weeks between injury and surgery were associated with an increased prevalence of medial meniscal tears. Dumont et al[9] found that 53.5% of pediatric patients who underwent ACL reconstruction >150 days after injury were found to have medial meniscal injuries at the time of surgery, compared with 37.8% of patients treated in <150 days. Furthermore, studies of the natural history of the knee after nonoperative management have demonstrated an increased likelihood of subsequent injury.[28] Treatment with bracing and rehabilitation is associated with decreasing knee function, especially in populations where it is difficult to control activity level.[2] In a radiographic-based cohort study of skeletally immature patients who underwent nonoperative management, there was a 19.5% chance of developing a meniscal injury that was not related to the initial injury.[28] Of those treated with nonoperative management, 32% ultimately underwent reconstruction due to recurrent instability, meniscal injury, or significant reduction in postinjury activity level.

Conventional adult reconstruction techniques pose a risk of growth arrest and deformity secondary to physeal damage when used in patients with remaining skeletal growth. Animal studies have been used to try to identify the threshold for physeal trauma and the effects of drill tunnel size,[13,14] filling,[3,23] and fixation hardware.[5,7] Subsequently, nonanatomic reconstruction techniques have been developed to avoid tunnel placement through the femoral and tibial physes.[4,20,26] Case reports and small cohort studies do show ACL reconstruction with minimal physeal drilling and specific hardware placement produces satisfactory outcomes with sparse instances of growth arrest.[12,18,25]

While ACL reconstruction in the pediatric patient may present certain challenges that are not present in the adult or skeletally mature patient, it has been shown that traditional techniques may be performed safely in patients with limited growth remaining.[11] Other techniques have demonstrated to be safe and efficacious in patients with significant growth remaining, including physeal-sparing, partial transphyseal, and as previously mentioned, those techniques that meticulously limit the amount of physeal disruption.[2,13,17,19,24]

While the adult literature is replete with studies regarding ACL injury management, research regarding management of ACL injuries in skeletally mature and immature adolescents is limited. The purpose of this study was to further define the factors that contribute to concomitant intra-articular injury in the setting of a pediatric or adolescent complete ACL tear. We aimed to compare and contrast the prevalence, severity, and management of the concomitant knee injuries among subjects with remaining growth potential (age ≤14 years) versus skeletally mature subjects (age >14 years). We anticipated that concomitant injuries would be more prevalent in older versus younger subjects. We also hypothesized that a delay to surgery would be a significant predictor of the presence of a concomitant knee injury that required additional operative procedures.

METHODS

After institutional review board approval was received, International Classification of Diseases, 9th Revision (ICD-9) diagnostic and procedural codes were used to identify all subjects who underwent primary ACL reconstruction at a single tertiary pediatric hospital between July 2005 and December 2012. Demographics and clinical characteristics were retrospectively collected from all subjects less than 19 years of age at the time of initial injury. Subjects were excluded based on the following: missing information, history of previous knee trauma, ACL reconstruction at an outside hospital, and/or chronic ACL deficiency. A summary of subject enrollment is described in greater detail in Figure 1. To create cohorts that were comparable with those previously reported in the literature, we stratified our patient population into older (14-19 years of age at initial injury) and younger (≤14 years of age at initial injury) cohorts.[22,27]

Clinical and demographic variables of interest included age at injury, race, sex, injury laterality, whether or not subject returned to activity before surgery, whether or not subject was given a brace before surgery, body mass index (BMI) percentile, grade of the intraoperative Lachman test, and time (in months) from initial injury to surgery. The BMI percentiles were calculated using a publically available program on the Centers for Disease Control and Prevention's website.[6] Obesity was defined as a BMI ≥95th percentile.[21] The operative reports and intraoperative imaging were reviewed for purpose of identifying all concomitant injuries to the knee joint. The location, severity, and treatment of all additional injuries were recorded. The severity of the chondral injuries was graded (I to IV) according to methods described by Outerbridge.[30] The severity of the meniscal injuries was graded based on the following: nonsurgical tear, tear requiring debridement only, reparable tear, irreparable tear (partial and/or complete meniscectomy). The presence of a concomitant knee injury that required additional operative treatment was the primary variable outcome of interest.

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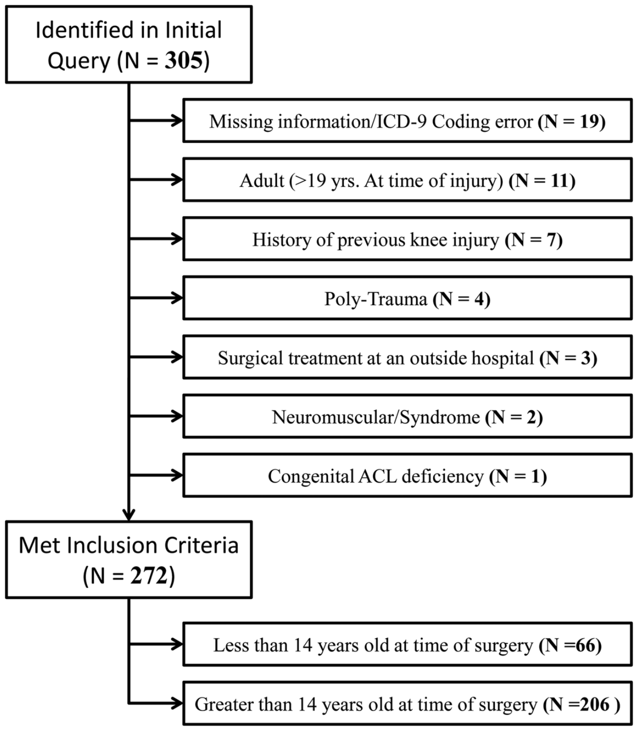

Figure 1. Summary of subject enrollment.

Statistical Analyses

The demographics, clinical characteristics, prevalence of meniscal injuries, and prevalence of chondral injuries in the younger and older cohorts were compared using chi-square tests or Student *t* tests, as appropriate. Univariable logistic regression analyses were then used to identify factors related to the presence of a concomitant injury that required additional operative treatment in each of the respective cohorts. We elected to stratify the analysis because of significant differences in the prevalence of concomitant injuries as well as significant differences in injury treatment patterns between the older and younger subjects. Three months was selected as the cutoff for defining a delay in surgery because based on a sensitivity analysis, this cutoff point was associated with the highest area under the curve value compared with all other potential cutoff points evaluated (2, 4, 5, 6, or 7 months). Factors significant at the alpha level of 0.10 in the univariable analysis were considered for inclusion in the final model. After a backward selection strategy, only variables significant at the 0.05 alpha level were included in the final multivariable logistic regression models. Kaplan-Meier time-to-event models were used to explore relation between the time as a continuous variable and the severity of the meniscal and chondral injuries.

RESULTS

A total of 66 and 165 subjects were included in the younger (age, ≤14 years of age at time of initial injury; range, 7-14 years) and older (age, 14-19 years of age at time of initial injury) cohorts, respectively. There was no significant difference in the demographics or clinical characteristics between the 2 groups (Table 1).

Meniscal and Chondral Injury Prevalence and Treatment Patterns in the Younger Versus the Older Cohort

There was a significant difference in the prevalence of all meniscal injuries that did or did not require additional operative procedures in the younger cohort (60.6%) compared with the older cohort (73.8%) (*P* = .0408; odds ratio [OR] = 1.83; 95% CI, 1.02-2.29). There was no significant difference in the prevalence of all chondral injuries that did or did not require additional operative procedures in the older (31.6%) versus younger (21.2%) cohorts (*P* = .1073). A significantly greater proportion of patients in the older cohort (65.1%) as compared with the younger cohort (48.5%) required additional operative procedures during the primary ACL reconstruction (*P* = .0163; OR = 1.98; 95% CI, 1.13-3.47). Additional injuries noted at time of surgery were 4 medial collateral ligament (MCL) injuries in the older cohort, of which 3 underwent surgical repair. Three patients in the older cohort had arthroscopic removal of cartilaginous loose bodies, and 1 had an osteochondral lesion that was managed arthroscopically. Additional injuries in the younger cohort included only 1 nonoperatively managed MCL grade II injury. A complete description of all meniscal and chondral injuries observed in the older and younger populations is described in Tables 2 and 3, respectively.

Factors Predictive of Concomitant Knee Injuries Requiring Additional Operative Treatment

Younger Cohort. Among subjects ≤14 years of age at the time of injury (younger cohort), a delay in surgery >3 months (*P* = .0027) and a return to activity before surgery (*P* = .0075) were identified as significant independent predictors of the presence of a concomitant injury that required additional operative procedures in the univariable analysis. A subjective report of 1 or more instances of knee instability before surgery (*P* = .0884), obesity (*P* = .1966), and patient sex (*P* = .8221) were not significantly related to the presence of a concomitant injury that required additional operative procedures in the univariable analysis. In the final multivariable model, a delay in surgery was the only significant predictor of the presence of a concomitant knee injury requiring additional operative procedures. Among subjects who underwent surgery >3 months after their initial injury, the odds of a subject with a chondral and/or meniscal injury that required additional operative procedures were 4.75 (95% CI, 1.70-14.37; *P* = .0027) times the odds of additional procedures among subjects who underwent surgery less than 3 months after their initial injury. Additional information about concomitant injuries identified in subjects who underwent surgery less than 3 months versus greater than 3 months after their initial injury is displayed in Tables 2 and 3.

TABLE 1
Demographics and Clinical Characteristics[a]

	Younger Cohort (age, ≤14 y)	Older Cohort (age, 14-19 y)	*P*
Sex			.8323
Female	30 (45.45)	95 (46.12)	
Male	36 (54.55)	111 (53.88)	
Laterality			.2712
Left	29 (44.62)	107 (52.45)	
Right	36 (55.38)	97 (47.55)	
Race			.1232
Asian	0 (0.00)	3 (1.47)	
Black	4 (6.15)	18 (8.82)	
White	53 (81.54)	135 (66.18)	
Other	8 (12.31)	48 (23.53)	
Return to activity			.1063
Returned	32 (48.48)	115 (59.90)	
Did not return	34 (51.52)	77 (40.10)	
Subjective report of instability			.3122
No instability	14 (21.21)	55 (27.50)	
Instability	52 (78.79)	145 (72.50)	
Lachman intraoperative grade			.2316
Not documented	7 (11.11)	10 (5.03)	
Grade II	7 (11.11)	23 (11.56)	
Grade III	49 (77.78)	166 (83.42)	
Obesity			.7116
No	52 (81.25)	169 (83.25)	
Yes	12 (18.75)	34 (16.75)	

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

Older Cohort. Among subjects greater than 14 years of age, a return to activity before surgery ($P = .0017$) and a delay in surgery >3 months were identified as significant independent predictors of the presence of a concomitant knee injury requiring additional operative procedures in the univariable analysis. Patient sex ($P = .2661$) and a subjective report of 1 more or more instances of knee instability before surgery ($P = .3168$) were not significantly related to the presence of a concomitant injury that required additional operative procedures. In the final multivariable analysis, obesity and a return to activity before surgery were significantly related to the presence of a concomitant knee injury that required additional operative procedures. After controlling for obesity, the odds a concomitant knee injury that required additional operative treatment among subjects who returned to activity before surgery were 3.86 (95% CI, 1.52-11.9; $P = .0034$) times the odds of additional treatment among subjects who did not return to activity before surgery. After controlling for a return to activity before surgery, the odds of a subject having a concomitant knee injury that required additional operative treatment among obese subjects were 2.59 (95% CI, 1.05-7.38; $P = .0381$) times the odds of additional treatment among non-obese subjects.

Relationship Between Severity of Injury and Time to Surgery

Time to event analyses were also used to explore the relationship between the time to ACL surgery and the severity of the meniscal and chondral injuries noted in the 2 cohorts (Table 4). In the younger cohort, there was a significant ($P < .0001$) relationship between time to surgery and meniscal injury severity. Time to surgery was significantly different between subjects who developed an irreparable meniscal tear versus a nonsurgical tear ($P < .0001$) or a reparable tear ($P = .0184$). There was also a significant difference in time to surgery between subjects who developed a reparable tear versus a nonsurgical tear ($P = .0323$). Among subjects in the younger cohort, there was a significant difference in time to surgery between subjects who developed severe (II, III, or IV) versus less severe (type I) chondral lesions. Additional information related to the differences in time to surgery based on concomitant injury severity is described in Table 4.

In the older cohort, there was a significant ($P < .0001$) relationship between time to surgery and meniscal injury severity. There was a significant difference in time to surgery between subjects who developed an irreparable meniscal tear compared with a nonsurgical tear ($P < .0001$) or a reparable tear ($P = .0012$). However, there was no difference in time to surgery between subjects who developed a nonsurgical tear versus a reparable tear ($P = .1934$). In the older cohort, there was also no difference in time to surgery among subjects who developed a severe versus a less severe chondral lesion ($P = .8877$).

DISCUSSION

The purpose of this study was to further define the factors that contribute to concomitant intra-articular injury in the

TABLE 2
Prevalence and Treatment of Meniscal Injuries[a]

	Younger Cohort (age, ≤14 y)			Older Cohort (age, 14-19 y)		
	Delay (n = 27)	No Delay (n = 39)	*P*	Delay (n = 56)	No Delay (n = 150)	*P*
Lateral meniscus						
Repair	3 (11.1)	2 (5.1)		9 (16.1)	18 (12.0)	
Partial meniscectomy	11 (40.7)	10 (25.6)		24 (42.9)	50 (33.3)	
Total[c]	14 (51.9)	11 (28.2)	.0515	32 (57.1)	68 (45.3)	.1313
Medial meniscus						
Repair	5 (18.5)	2 (5.1)		7 (12.5)	17 (11.3)	
Partial meniscectomy	9 (33.3)	2 (5.1)		15 (26.8)	9 (8.0)	
Total[c]	12 (44.4)	4 (12.3)	.0014	21 (37.5)	29 (19.3)	.0068

[a]Values are reported as n (%).
[b]Includes debridement.
[c]Total represents number of subjects who underwent 1 or more surgical procedures.

TABLE 3
Prevalence and Treatment of Chondral Injuries[a]

	Younger Cohort (age, ≤14 y)			Older Cohort (age, 14-19 y)		
	Delay	No Delay	*P*	Delay	No Delay	*P*
Femoral condyle						
No treatment[b]	5 (18.5)	3 (7.7)		14 (24.6)	15 (10.1)	
Chondroplasty	3 (11.1)	0 (0.0)		14 (24.6)	10 (6.7)	
Microfracture	0 (0.0)	0 (0.0)		2 (3.5)	1 (0.7)	
Total	7 (25.9)	3 (7.7)	.0773	25 (43.9)	22 (14.8)	<.0001
Tibial plateau						
No treatment[b]	3 (11.1)	1 (2.6)		7 (12.3)	8 (5.4)	
Chondroplasty	2 (7.4)	0 (0.0)		4 (7.0)	4 (2.7)	
Microfracture	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Total	5 (18.5)	1 (2.6)	.0379	11 (19.3)	11 (7.4)	.0109
Patella						
No treatment[b]	1 (3.7)			3 (5.3)	1 (0.7)	
Chondroplasty	0 (0.0)	0 (0.0)		1 (1.8)	6 (4.0)	
Microfracture	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Total	1 (3.7)	0 (0.0)	>.999	4 (7.0)	7 (4.7)	.4948

[a]Values are reported as n (%).
[b]Represents injuries that were noted intraoperatively but did not require additional operative procedures

setting of a pediatric or adolescent complete ACL tear. This study is unique in that we compared and contrasted the prevalence and treatment of concomitant knee injuries in a cohort of patients greater than 14 years of age relative to a cohort of patients less than 14 years of age who underwent operative treatment at a single pediatric institution. We have included a large amount of data that have been lacking from prior studies, including subanalysis of severity, location of injury, and treatment. We also sought to describe the effect that factors such as obesity, subjective instability, and a return to sport have on the development of concomitant knee injuries. In this population of patients who underwent primary ACL reconstruction, patients older than 14 years tended to have more chondral and meniscal injuries than subjects younger than 14 years.

The risk factors associated with the development of a concomitant knee injury that required additional treatment were also different among older versus younger children. In the younger cohort, a delay in surgery longer than 3 months was identified as the strongest predictor of the presence of a concomitant knee injury that required additional treatment. In contrast, obesity and a return to activity before surgery were identified as the strongest predictors of the presence of a concomitant knee injury that required additional operative treatment in the older cohort. We suspect that differences in activity level and compliance with activity restrictions may explain the injury patterns in the 2 populations. Younger patients may be less compliant with activity restrictions and more likely to engage in activities outside of participation in organized sport that result in the development of

TABLE 4
Time to Surgery Based on Injury Severity[a]

	Median Time to Surgery, mo	
	Younger Cohort (age, ≤14 y)	Older Cohort (age, 14-19 y)
Severity of meniscal injuries		
Nonsurgical tear	1.71 (0.69-2.17)	1.15 (0.89-1.48)
Reparable	3.15 (1.58-11.07)	1.69 (1.28-2.23)
Irreparable tear	10.15 (2.53-33.84)	2.23 (1.91-3.12)
Severity of chondral injury		
Type I	5.95 (0.66-37.13)	2.94 (1.48-5.03)
Type II, III, or IV	33.4 (1.97-44.91)	2.6 (1.54-4.37)

[a]Values in parentheses are 95% CI.

subsequent knee injuries. In older patients, subsequent knee injuries likely occurred after a return to organized sports and/or sport-related activities, especially among the heavier individuals. However, based on the data collected in the current study, it is not possible to draw definitive conclusions regarding the differences in risk factors between the 2 populations.

In both cohorts, a delay in surgery was associated with meniscal injury severity. Furthermore, when stratified based on the location of the injury, a delay in surgery greater than 3 months was significantly associated with the presence of a medial meniscal injury that required additional operative treatment in both the older and younger cohorts (Table 2). The relationship between a delay in surgery and the presence of lateral meniscal injury did not reach statistical significance. This is consistent with the findings reported by Lawrence et al[22] in which data were collected from 1991 to 2005 on patients 14 years and younger who underwent ACL reconstruction. The study found that time from injury to surgery was associated with an increase in the prevalence and severity of medial meniscal tears. In a patient population aged younger than 19 years, Dumont et al[9] reported a similar increase in medial meniscal tears when surgery was delayed (37.8% in the early treatment group compared with 53.5% in the delayed treatment group). In contrast to these studies,[9,22] we did not observe a significant association between subjective patient reporting of instability and the prevalence of concomitant knee injuries.

The timing of ACL surgery was significantly associated with chondral injury severity in the younger cohort only. These results suggest that chondral injuries in younger patients are the result of progressive damage to the articular surface of the knee. In contrast, older patients may sustain more severe damage at the time of the initial injury. Adult studies also report that increased age and a longer time from injury to reconstruction are associated with a higher risk for grade III and IV chondral lesions.[10,29,32] Whether differences in injury patterns are due to increased patient awareness, patient age–related stability, body control, or proprioceptive differences remains to be determined.

When comparing our study to the study by Dumont et al,[9] the stratification of the data does not allow for direct comparison. Their study has an impressive number of patients, but only the presence and location of concomitant injuries is reported. Our study builds on their data, with a focus on the severity and required treatment of concomitant injuries. This further documentation is more helpful to the surgeon, the eventual prognosis, and to direct treatment. In addition, the association in the Dumont et al[9] study with the patient's weight has been further defined in the present study to better determine those patients who are obese with respect to BMI in an effort to tease out pertinent risk factors, as suggested by their recommendation for future studies. The weight of a well-proportioned large patient may have less effect than the patient with an obese habitus, regardless of their weight. We did show that in the older cohort, obesity by a BMI metric did correlate with the need for additional procedures.

Studies on adult ACL reconstruction have reported that the presence of meniscal tears requiring additional operative treatment significantly increases if surgery is postponed, but the definition of delayed treatment varies between studies.[8,31,32] Research in children shows similar variability. Lawerence et al[22] reported a significant association between the presence of a concomitant knee injury and a delay in surgery greater than 12 weeks. Dumont et al[9] reported a significant association between medial meniscal injuries and delay in surgery >150 days (12.5 weeks). In our study, a delay in surgery greater than 3 months (approximately 13 weeks) was significantly associated with the development of a knee injury that required additional operative treatment. Despite differences in the definition of a delay in surgery, all 3 articles, including the present study, highlight the potential issues associated with a delay in surgery. When possible, operative fixation within 3 months of the initial injury may be beneficial in preventing the development of concomitant knee injuries that warrant surgical intervention.

The strengths of the study include the fact that this is the first study to compare concomitant knee injury prevalence in relatively skeletally immature patients to a cohort of skeletally mature adolescent patients treated in a single children's hospital. This comparison eliminates the inherent bias of prior studies that compare the younger patients to those who were treated at different facilities by different surgeons. Other strengths include the large number of total included patients and the relatively high rate of patients who were able to be included in the study. Only 3 of the patients offered surgery at our center elected to have their procedure done at an outside hospital, allowing for a relatively inclusive review of the population who presented to our hospital network. Furthermore, we have stressed the importance of the concomitant injury as it relates to requiring additional operative treatment. This allows analysis of those severe injuries that are most pertinent and limits the inclusion of relatively minor injuries that may not be consistently documented by the orthopaedic surgeon.

Weaknesses include the 19 patients who were excluded due to missing information. Also, the separation of the 2 groups based on the age of 14 is an arbitrary cutoff. Discreet analysis of the subjects' bone age and remaining growth was not possible in this study due to inconsistent preoperative radiographic studies. Future prospective studies that could include this information would be very helpful. Additionally, this study only focused on patients who elected to undergo operative treatment. Injury patterns among patients who opted for nonoperative treatment was not specifically studied.

CONCLUSION

Recent literature has demonstrated that like the adult knee, the pediatric knee that lacks native ligamentous stability is predisposed to further intra-articular damage. This study augments recently published data describing a delay in ACL reconstruction and concomitant injury in young adolescent populations. More importantly, this study draws attention to differences in the prevalence of concomitant knee injuries as well the factors related to these injuries in older versus younger populations. Among older populations, the development of concomitant knee injuries appears to be driven by a return to activity and increased body mass. In younger populations, a delay in surgery is the strongest predictor of the development of concomitant knee injuries that require additional operative treatment. More prompt identification and subsequent intervention may help to improve overall outcomes in both younger and older patients.

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