Treatment of Posterior Cruciate Ligament Injuries in Pediatric and Adolescent Patients

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Background: There is sparse literature regarding the outcomes of treatment for posterior cruciate ligament (PCL) injuries in pediatric and adolescent patients. PCL injuries are rare and are often treated conservatively. The purpose of this study was to review 2 separate cohorts of patients with pediatric and adolescent PCL injuries: those treated surgically with direct repair or ligament reconstruction and those managed nonoperatively.
Methods: Twenty-five patients 18 years or younger underwent treatment of 26 PCL injuries (1 bilateral) at a single institution between 1993 and 2009. Fourteen patients (15 knees) underwent operative treatment, while 11 patients were treated nonoperatively. Demographic and clinical features of each group were reviewed, and validated functional outcome measures [Pediatric International Knee Documentation Committee (Pedi-IKDC), Lysholm, and Tegner scores] were analyzed.
Results: Eleven patients (6 females; mean age, 14.4 y) who sustained PCL injuries were treated nonoperatively, At a mean clinical follow-up of 26.7 months, none of the patients who underwent nonoperative treatment had symptomatic instability, with a 100% return-to-play rate. The mean Pedi-IKDC, Lysholm, and Tegner scores were 87.4, 89.0, and 7.5, respectively. In the 15 knees of 14 patients who underwent surgery (4 female; mean age, 15.1 y) mean clinical follow-up was 27.8 months. All of the patients achieved full or near-full range of motion, and none of the patients showed growth arrest or angular deformity. However, 1 patient showed mild joint-space narrowing, and the mean Pedi-IKDC, Lysholm, and Tegner scores were 81.3, 80.1, and 7.2, respectively. Patients who had sustained knee dislocations had lower Pedi-IKDC scores than those who had not dislocated, 70.2 versus 85 ($P = 0.047$).
Conclusions: Outcomes for nonoperative treatment of partial PCL tears or nondisplaced avulsion injuries are good in young patients. PCL repair or reconstruction is a safe and viable treatment option in pediatric and adolescent patients with multiligament injuries or those with isolated PCL injury who have failed conservative treatment, with outcomes related to the severity of the initial injury.
Level of evidence: Level IV, retrospective case series.

Key Words: posterior cruciate ligament, PCL reconstruction, knee injury, ligament avulsion

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In recent years, anterior cruciate ligament (ACL) injuries in children and adolescents have received increased attention, both because of the recognition that these injuries are becoming more common than historically appreciated[1] and because surgical treatment presents unique challenges, with respect to graft placement and fixation in patients with open physes.[2–6] By contrast, posterior cruciate ligament (PCL) injuries are significantly less common overall and less well studied, particularly in the pediatric population. Although PCL injuries in adults have traditionally been managed more frequently with conservative means, a number of authors have described an evolution towards operative treatment, as appreciation of the natural history of the PCL-deficient knee has become better understood.[7–10] Likewise, nonoperative treatment has long been the first-line approach to PCL injuries in the pediatric population, partly because of the additional operative risks of physeal injury, which can lead to growth arrest or angular deformity. However, there remains a dearth of literature regarding the treatment of PCL injuries in young patients, and although several case reports and small series have suggested that operative treatment is a feasible management option in select cases,[11–15] to our knowledge no outcome studies have been published or algorithms established to comprehensively guide management decisions for patients in this population with PCL injuries. The purpose of this study was to review the experience at a single, tertiary children hospital with pediatric and adolescent PCL injuries treated operatively either with repair or reconstruction, and separately assess, in a noncomparative fashion, features of a similarly age-matched group of patients with PCL injuries that were managed nonoperatively.

METHODS

A departmental orthopaedic database was queried for patients' aged 18 years or younger seen at a tertiary care pediatric hospital between 1993 and 2009 with a

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diagnosis of PCL injury. On the basis of an Institutional Review Board-approved study design, medical records, including—preoperative and postoperative office visit assessment, operative reports, musculoskeletal radiologist-read radiographic and magnetic resonance imaging (MRI) reports, and associated images—were reviewed to assess for potential study candidates. Inclusion criteria consisted of PCL injury, aged 18 years or younger at the time of initial visit (for nonoperative cases) or surgery (for operative cases), and ability to complete validated functional outcome measure patient questionnaires. Exclusion criteria included patient aged older than 18 years, cases with incomplete medical records, or inability to complete informed consent. Nonoperative patients were age and sex matched with the operative group, this said, patients who responded to our mailings had to go through 2 rounds of inclusion eligibility filtration. Among sex-matched and age-matched nonoperative patients, 12 out of 14 completed the questionnaires giving us a response rate of 86%.

Two forms of follow-up were calculated; "clinical follow-up" relates to the time from the clinical follow-up visits calculated from the date of presentation or date of surgery to the date last seen in clinic for nonoperative and operative patients, respectively, whereas "functional outcome follow-up" refers to the time between surgery and the questionnaire completion.

The following data was collected for all included patients: mechanism of injury, date of injury, initial injury pattern based on MRI and intraoperative assessment, date of surgery, surgical procedure performed, additional procedures performed on the same knee, complications related to the surgery, subjective assessments of knee range of motion (ROM), results of posterior drawer testing, and Lachman testing. The diagnosis of partial tears versus complete tears was based on MRI findings, where a signal pattern suggestive of any portion of intact PCL collagen fibers were indicative of a partial PCL tear rather than a complete tear. For the operative cases, arthroscopic probing and inspection of the integrity of the ligament itself was used for definitive designation of complete or partial tear, but there were no instances in which an MRI-based diagnosis of a "partial tear" was changed to "complete tear" or a "complete tear" changed to "partial tear" after intraoperative evaluation. The time between injury and surgery was calculated, and the operative treatments were characterized as acute (surgery within 14 d postinjury), subacute (between 2 and 10 wk postinjury), or chronic (> 10 wk postinjury).

In the postoperative follow-up period, all operative patients were sent questionnaires, including the Pediatric International Knee Documentation Committee (Pedi-IKDC) form,[16] Lysholm Knee Score, and Tegner Activity Scale.

The modified Pedi-IKDC score is a validated outcome score of knee function specific for the pediatric population.[16] The Lysholm knee scoring scale is a validated functional measure introduced by Tegner and Lysholm[17] in 1985 that assesses the comfort related measures such as pain and swelling along with basic daily activities such as problems with stair climbing, general instability, limping, and knee locking. The Tegner Activity Score, introduced as well in 1985 by Tegner and Lysholm, is designed to measure the activity level in patients varying from limited activities, to daily living activities, recreational, and then competitive sports. The score is graded from 0 to 10 with 10 being the elite level in competitive sports.[17]

Standard scoring methodology was utilized for calculating Pedi-IKDC, Lysholm, and Tegner scores, and statistical analyses were performed on demographic data, surgical, and postoperative functional outcome measures, with categorical variables compared based on χ^2 tests and continuous variables based on 2-tailed Student t tests, with $P < 0.05$ being used for statistical significance.

RESULTS

From 1993 to 2009, 21 "surgical" patients who underwent either PCL repair or reconstruction met the inclusion criteria, with 14 patients providing postoperative functional outcome measures on their 15 knees (1 bilateral), for a response rate of 71% in the operative cohort. These 14 patients were then age-matched to 11 patients who were identified as having sustained PCL injuries, but who were managed over time with nonoperative measures. Mean clinical follow-up was 26.7 months (range, 9.1 to 57.6 mo) and 27.8 months (range, 8.2 to 144 mo), for nonoperative and operative patients, respectively.

Demographic information, mechanism of injury, injury pattern, activity at the time of injury and outcome measures for the nonoperatively and operatively treated patients are provided in Table 1.

Concomitant injuries were common in both subgroups of patients as presented in Table 2. Among the 3 nonoperatively treated patients with concomitant meniscus injuries, 1 patient later underwent an arthroscopic partial meniscectomy; 1 patient had an arthroscopic meniscus repair, and the third patient remained asymptomatic with no intervention. In the 15 knees treated surgically, 7 knees (47%) had open physes and 8 (53%) had closed physes. Among 8 patients with multiligamentous injuries, 5 (33%) had knee dislocations.

Using a combination of preoperative radiographic and MRI, operative note descriptions, and arthroscopic digital photographs, it was determined that of the 8 femoral avulsion injuries, the proximal aspect of the PCL contained only a chondral fragment in one 4-year-old child, a bony fragment in 3 patients (15, 16, and 18 y old), no bone or cartilage in 2 patients (16 and 17 y old), and incomplete imaging or records to definitively determine the size and tissue type in 2 patients. The average size of the fragment was $12.5 \times 9.2 \times 3.9$ mm (range, greatest dimension: 10 to 20 mm, smallest dimension: 1.5 to 7 mm). Of the 2 tibial-sided avulsion-type injuries, both involved bony fragments, with sizes of $10 \times 6 \times 5$ mm and $20 \times 16 \times 1.5$ mm, respectively.

TABLE 1. Presentation of Operative and Nonoperative PCL Injury Cases

	Operative Knees (n = 15)	Nonoperative Knees (n = 11)
Sex n (%)		
Male	11 (73)	5 (45)
Female	4 (27)	6 (55)
Age mean (range in y)	15.1 (4-18.3)	14.4 (7.4-17.5)
Mechanism of injury n (%)		
Twisting/noncontact	5 (33)	4 (36)
Direct blow	10 (67)	7 (64)
Activity at time of injury n (%)		
Sports (football, basketball, skiing, biking, soccer, track, sledding, and roller skating)	6 (40)	8 (73)
Gymnastics	1 (7)	2 (18)
Playground (monkey bars, and fall from heights)	2 (13)	1 (9)
Hyperextension (trampolines)	4 (26)	0 (0)
Motor vehicle accident	2 (13)	0 (0)
Injury pattern n (%)		
Partial tear	1 (7)	8 (73)
Complete mid-substance tear	4 (27)	1 (9)
Min. displaced bony avulsions	10 (67)	2 (18)
Outcome measurement scores mean, (range)		
Pedi-IKDC	81.3 (53.2-97.8)	87.3 (64.7-100)
Tegner	7.7 (0-10)	7.5 (6-9)
Lyscholm	80.1 (52-100)	89 (58-100)

PCL indicates posterior cruciate ligament; Pedi-IKDC, Pediatric International Knee Documentation Committee.

Timing of surgery was variable, with a median time of 36 days between injury and surgery, and a mean of 131 days, which was elevated by several outliers with long delays before seeking operative treatment. Four out of 15 knees (27%) underwent operative intervention in the acute postinjury period, 6 (40%) were performed subacutely, and 5 (33%) in the chronic phase. All "subacute" patients were given a postinjury, preoperative physical therapy regimen designed to improve ROM, similar to contemporary preoperative ACL injury protocols. In the 5 "chronic" patients, definitive conservative treatment had been attempted for prolonged periods, but in each case, patients remained symptomatic with pain, instability, and an inability to return to their preinjury activity level.

TABLE 2. Concomitant Injury Patterns in Operative and Nonoperative Subjects

	Operative Knees (n = 15)	Nonoperative Knees (n = 11)
Injury n (%)		
Isolated PCL injuries	7 (47)	6 (55)
Concomitant ligament injuries	8 (53)	2 (18)
Meniscus injuries		
Medial	6 (40)	3 (27)
Lateral	2 (13)	0 (0)
Medial and lateral	1 (7)	0 (0)
Tibial plateau fracture	1 (7)	2 (18)
Patellar dislocation	2 (13)	0 (0)
Femoral condyle chondral injury		
Grade 2 medial	1 (7)	0 (0)
Grade 2 lateral	1 (7)	0 (0)
Grade 3 lateral	1 (7)	0 (0)

PCL indicates posterior cruciate ligament.

Three different surgeons performed the operations, with a wide variety and combination of techniques utilized. Primary PCL repair with suture fixation techniques was performed in 5 knees, screw fixation of an avulsed tibial fragment in 1 knee, and reconstruction with Achilles tendon bone-block allografts in 8 knees. In 1 knee, for which arthroscopy was indicated to address a full thickness cartilage lesion of the medial femoral condyle, no bony fragment was identified on a partially avulsed PCL. Therefore a "healing response" technique was utilized, as previously described for treatment of femoral ACL avulsion, in which the femoral PCL footprint underwent microfracture adjacent to the intact fibers.[18] All 5 of the "chronic" patients' knees were among the 8 knees that underwent reconstruction, rather than repair. Of those PCL injuries that underwent suture fixation repair techniques, all were on the femur and involved either 1 or 2 suture anchors into the femoral PCL origin in the notch (n = 2) or drill holes made with a PCL drill-guide (n = 3), through which 2 sutures, arthroscopically placed through the proximal aspect of the PCL, were passed and tied over a button on the medial cortex of the femoral condyle through a mini-open, subvastus approach. All PCL procedures were performed primarily with arthroscopic techniques, except for 1 that was converted to an open anterior arthrotomy to improve tensioning of suture fixation of an avulsed femoral-sided PCL fragment. All concomitant ACL injuries underwent reconstruction, whereas 2 out of 4 medial collateral ligament injuries and 2 out of 3 lateral collateral ligament injuries, respectively, were repaired in either concomitant or staged procedures. To address the 10 concomitant meniscus tears seen in 9 of the 15 total knees, 6 partial meniscectomies (5 medial and 1 lateral) and 4 meniscus repairs (2 medial and 2 lateral) performed. The medial femoral condyle and 2 lateral femoral condyle cartilage injuries underwent chondroplasty.

Several complications were observed in the series of operative patients. One patient who suffered a concomitant hip dislocation at the time of his knee injury was diagnosed with partial sciatic nerve palsy in the peroneal distribution preoperatively, and had significant, but incomplete, resolution of motor function of the tibialis anterior. Three patients developed arthrofibrosis, 2 of which underwent arthroscopic lysis of adhesions and 1 underwent manipulation under anesthesia, leading to significant improvement in ROM in all cases. All 3 patients had undergone surgery in the "acute" period after injury and their mean time between injury and surgery (1.4 wk) was significantly shorter than those not developing arthrofibrosis (23.5 wk; $P = 0.008$).

Functional outcome measures and activity scores were collected for both the nonoperative and operative

patients, at a mean of 44 months (median, 36; range, 23 to 72 mo) and a mean of 58 months (median, 36; range, 16 to 192 mo), respectively. No patient whose PCL injury was treated nonoperatively complained of symptomatic instability. All 11 reported return-to-play rate and no patients had sought surgery for instability or knee pain at the time of final follow-up. Data related to the outcome for operative patients is summarized in Table 3. One knee, in the patient who sustained concomitant ACL tear, lateral meniscus tear, and mildly impacted tibial plateau fracture which was treated nonoperatively, demonstrated early degenerative radiographic signs, including mild medial and lateral joint-space narrowing and small medial femoral condyle and lateral femoral condyle osteophytes. This patient also demonstrated the lowest IKDC and Lysholm scores of all patients.

With respect to Pedi-IKDC scores as presented in Tables 1 and 3, when these scores are subcategorized according to injury type, the knee dislocations had lower functional outcome than those that did not dislocate in every outcome measure, although this was a statistically significant finding only for Pedi-IKDC scores: Pedi-IKDC 70.2 versus 87, respectively ($P = 0.047$), Tegner 6.0 versus 8.7 ($P = 0.22$), and Lysholm 69.8 versus 85.8 ($P = 0.13$). There was no significant difference in the outcome or activity level of patients who had developed arthrofibrosis in the early postoperative period versus those who had not, in older than 15 years versus 15 years or younger, or in those who underwent surgery in the chronic phase, versus those in the acute or subacute phases (Table 4).

TABLE 3. Outcomes of Surgical Treatment

	No. Knees n (%)
Range of motion	
Full	12 (80)
Near-full	1 (7)
Not reported	2. (13)
Posterior drawer instability	
Solid end-point	15 (100)
IKDC grade*	
A	1 (7)
B	10 (67)
C	2 (13)
D	0 (0)
Not reported	2 (13)
Radiographic	
Normal alignment/no angular deformity	9 (60)
Physeal arrest/bony bar formation	0 (0)
No radiographic data reported	6 (40)
Outcome scores	
Pedi-IKDC	
≥ 90	5 (33)
80-89	3 (20)
70-79	5 (33)
< 70	2 (13)
Lyscholm	
84-100	5 (33)
65-83	9 (60)
< 65	1 (7)
Tegner	
≥ 7	12 (80)
≤6	3 (20)

*IKDC classification system for postoperative grading of stability by posterior drawer testing (A: 0-2 mm manual posterior tibial translation relative to femoral condyles, with knee in 70-degree flexion; B: 3-5 mm; C: 6-10 mm; D: > 10 mm).

Pedi-IKDC indicates Pediatric International Knee Documentation Committee.

DISCUSSION

Although the subject of ACL injuries in pediatric and adolescent patients has received increasing attention in the past decade,[2–6] studies surrounding PCL injuries in children have remained sparse. In the adult literature, an expanding number of studies have suggested that PCL injuries, which have historically been managed commonly by nonsurgical treatment approaches, may be associated with more instability and degenerative knee problems than previously appreciated.[7–10] Moreover, as arthroscopic instrumentation, technical capabilities, and understanding of PCL anatomy and function have all been advanced, outcomes of PCL reconstruction in adults have improved in kind. Nevertheless, surgical treatment of acute PCL tears and PCL deficiency remains highly controversial, both with regard to how effectively knee instability and osteoarthritis may actually be prevented with operative interventions,[19] as well as what represents the optimal technique. Conflicting studies have emerged on a full spectrum of technical considerations for PCL surgery in adults, such as single-bundle versus double-bundle reconstruction,[20,21] transtibial versus tibial inlay approaches,[22,23] and allograft versus autograft for reconstruction material.[24,25]

By contrast, because PCL injuries are significantly less common in children, little comparative research and few technical investigations have emerged in the pediatric literature. The dearth of investigations on surgical treatment of PCL injuries in pediatric and adolescent populations may reflect not only a lower injury incidence, but also an appropriately conservative approach, given the additional operative risk of physeal injury, which can lead to growth arrest or angular deformity. Moreover, unlike mid-substance tears in which the PCL is consistently debrided and reconstructed in adults, there is some evidence that PCL injury patterns are more varied and potentially

TABLE 4. Subjects Mean Age Per Type of Initial Surgical Procedure

	No. Knees n (%)	Mean Age (y)
Type of Surgery		
Primary suture repair (femoral suture anchor + bioabsorbable screw)	01 (07)	04.6
Primary suture repair (femoral suture anchor × 2)	01 (07)	05.7
Primary suture repair (through drill holes)	03 (20)	16.5
"Healing response" (microfracture of femoral footprint)	01 (07)	17.0
Reconstruction (with Achilles allograft)	08 (60)	16.5
ORIF of PCL fragment (tibial side)	01 (07)	17.4

ORIF indicates open reduction and internal fixation; PCL, posterior cruciate ligament.

more complex in the younger population, as some combination of periosteal, chondral, ligamentous, and osseous injury can occur, warranting a variety of treatment approaches, the selection of which should necessarily depend on the specific findings.[13,26–28] However, if significant instability and degenerative changes are indeed sequelae of PCL deficiency in adults, then optimization of treatment is all the more critical in this younger, more active population, with the hope of future decades of preserved knee function. Therefore, just as natural history studies of ACL injury and deficiency in children have elucidated the importance of more significant interventions and prompted acceleration of reconstructive techniques that accommodate for physeal anatomy and future growth, so too should awareness of PCL injuries in children increase, as well as our abilities to treat them surgically, if warranted.[1,29,30] Although epidemiological studies in this particular area are lacking, it seems likely that the same forces responsible for the increases in anterior cruciate injuries—increased participation in youth sports, higher intensity of play, more year-round, single-sport, repetitive activity and overuse patterns, improved injury recognition, better diagnostic methods—will have a similar effect on PCL injuries as well, though likely on a smaller scale.[31]

The current study was designed to analyze the breadth of experience over a 17-year period with PCL injuries at a single, tertiary care children's hospital, with a focus on cases undergoing operative intervention. Although outcome measures were collected for the control group of nonoperatively managed PCL injuries, 1 limitation of the study is that direct statistical comparisons, particularly of outcome measures, would not be appropriate between the 2 groups, as their treatments were selected specifically for the confounding differences between them. Nevertheless, several trends between the 2 are worth noting. For example, 73% of the nonoperative group had partial PCL tears, compared with 1 patient in the operative group, who underwent surgery primarily for a nonligamentous concomitant injury. Although a number of studies support the idea that partial ACL tears in adults should more often be treated with reconstruction, Kocher and colleagues demonstrated that the majority of patients with partial ACL tears in the pediatric population will do well without surgery, with the exception of the select group of older adolescents, those with significant instability, and those with tearing of $>50\%$ of the ligament substance.[32–35] Few studies provide guidance on treatment of partial PCL injuries, specifically, although studies in adults generally favor nonoperative treatment.[36,37] Likewise, the fact that none of the 8 patients in the current series treated nonoperatively for partial tears complained of instability or required surgery at >2 years mean follow-up generally speaks to a recommendation of nonoperative treatment of partial PCL tears in children and adolescents. Unlike the comparable injury in ACL injury, because of the relative success of this approach, no risk factors for failure were identified in this cohort of young patients with partial PCL tears.

The injury patterns in the nonoperative and operative group also warrant comparison. Two of the patients treated with conservative measures, 11- and 14-years-old, respectively, were found to have bony avulsion fractures at the tibial insertion site of the PCL. However, in both instances there was minimal displacement of the fragment, compared with the complete displacement seen in all of the patients with bony or cartilaginous avulsions in the operative group, which represented 67% of the cohort. This conservative treatment approach is consistent with historical recommendations, which suggest that nondisplaced or minimally displaced avulsion injuries can be treated with immobilization, whereas displaced avulsion fractures warrant ORIF.[38] However, only 1 of the 10 avulsions treated operatively in our series underwent the isolated screw fixation historically recommended. Rather, suture fixation techniques—either with the use of suture anchors, or suture placed through transcondylar drill holes tied over cortical, extra-articular buttons—were used for half of avulsion injuries, with allograft reconstruction pursued for the others. Similar to the evolution of treatment of ACL avulsion injuries in children involving tibial spine fractures, for which some authors have begun to favor suture fixation over screw fixation, suture-based repairs of PCL avulsion injuries may more easily avoid issues with permanent hardware causing impingement, imposition of rigid forces by hardware on physeal growth, or a required additional future procedure, in the form of removal of implants, which creates cost and risk for the patient.[39–41] However, because of the rarity of PCL injuries, no studies have compared these techniques directly.

Interestingly, 80% of the avulsion injuries in the current pediatric and adolescent cohort involved the femoral side of the PCL, whereas Kim et al[42] reported on their treatment of tibial-sided avulsions in an adult-based cohort of 13 patients, in which only 1 patient was younger than 18 years, as well as a separate series of 6 pediatric patients with tibial "peel-off" injuries.[23] In contrast, the same authors published only a single case report of a femoral-sided avulsion in a 42-year-old man.[26,43] Similar to the 6 tibial-sided avulsion fragments described by Kim and colleagues, all of which were cartilage tissue alone, one of the patients in our series, a 4 year old, demonstrated a purely cartilaginous fragment as well. Although those authors suggest that age-dependent failure patterns may exist for PCL injuries in children, we would conjecture that both mechanism and energy of injury are likely to play variable roles as well.[26] While the limited sample size of the current study precluded sophisticated substratified analyses of injury patterns, it was notable that each of the following patterns occurred in our subset of operative patients who were between ages of 14 to 18, with a variety of contact and noncontact mechanisms at work: mid-substance tears, pure ligamentous avulsions, and bony avulsions of various sizes, on both the tibial and femoral sides. As a result, no definitive age-based associations or trends were able to be derived from our investigation. However, despite the description by

Kim et al[42] of 13 avulsion injuries in adult patients with a mean age of 35 years (range, 17 to 57 y), and despite the presence of 5 mid-substances tears that were seen in the adolescent age group in our series, we believe that avulsion-type injuries, both cartilaginous and bony in nature, are significantly more common in a younger pediatric and adolescent age group, when compared with the more common mid-substance tears of adults, as this is a well-established age-based distinction in a variety of injury types and anatomic sites.

Notably, primary repair with suture fixation technique was utilized in only one 16-year-old male patient in our series who had a purely ligamentous femoral-sided avulsion-type injury. Although histologic analysis was not performed, it is possible that a thin layer of fibrocartilage or calcified cartilage may have remained attached to the ligament and once refixed to its original bony bed, allowed for healing at a similar rate to the other injury patterns. Other authors have described a similar type of injury previously on the femoral side of the PCL.[43,44] In most instances in our series, however, suture fixation was able to be performed in the setting of a sizeable bony or cartilaginous fragment on the avulsed side: the mean diameter in the longest dimension was 12.5 mm, with a mean thickness of 4 mm. Although hematoma and fibrous tissue often need to be debrided from the notch and the fragment, we found it important to avoid debridement of any substantive portion of the cartilage or bone itself, as arthroscopic observation of the morphology of the fragment facilitated an anatomic reduction to its bony bed and recreation of normal tension of the ligament.

Of the 2 tibial-sided avulsion injuries managed operatively in our series, 1 was treated with transtibial allograft reconstruction and the other with arthroscopic-assisted screw fixation. Although there is considerable debate in the adult literature regarding transtibial versus tibial inlay techniques, most reports in the pediatric literature have focused on transtibial-based techniques, whether primary repair or reconstruction is pursued.[26,42] However, Bovid et al[12] reported on an all-arthroscopic tibial inlay technique of PCL reconstruction in an 11 year old with a mid-substance tear, in whom good results were seen at 17 months follow-up. The authors note that their technique was modified to decrease the chances of physeal injury, which is of critical importance when managing skeletally immature patients with PCL injuries. Although our series included 7 skeletally immature knees, 4 of the 5 knees that were seen to have closing physes—in pubescent patients—underwent allograft PCL reconstruction, rather than primary repair. This approach was selected based on principles derived from a study investigating ACL in patients who are nearing skeletal maturity, in which no cases of physeal bar or angular deformity were seen when soft-tissue grafts were placed across physes in pubescent patients.[45] However, primary ligament repair techniques were pursued in 2 patients with wide open physes (ages 4 and 5 y, respectively) and 1 patient with imaging demonstrating a closing physes (15-y-old male). Suture anchors were placed from the notch into the medial femoral condyle at the origin of the PCL in the former 2 patients, thereby eliminating any concern related to drilling or the creation of tunnels. In the latter patient, the drill holes were made through the medial femoral condyle with a 2.7-mm drill bit. While considerations of physeal avoidance is not as relevant to a femoral-sided repair, in which the ligament attachment is distal to the physis, we believe that tibial-sided repairs can be made with transtibial technique using similar small drill holes, as described by Kim et al,[26] based on the animal studies which have shown that the chances of physeal disruption are minimized if $<7\%$ of the total physeal area is crossed.

Approximately half of the knees in the current operative cohort had multiligament knee injuries, and one third sustained frank knee dislocations. Although the frequent presence of concomitant knee pathology somewhat confounds our ability to analyze the effect of interventions related specifically to the PCL injury, it may also speak to the relative rarity of isolated PCL injuries warranting surgical intervention in this age group. For example, most of the reports in the literature related to pediatric PCL injury are case reports or describe multiple concurrent knee injuries. Clanton et al[13] reported on 9 children with knee ligament injuries, only 1 of which was a PCL avulsion injury from its femoral attachment that was repaired with suture through drill holes with a good result. Anderson and Anderson[11] described the case of a 13-year-old boy with a chronic PCL injury and posterolateral instability, who was treated with a physeal-sparing, double-bundle PCL reconstruction with hamstring autograft, lateral collateral ligament reconstruction with tibialis anterior allograft, and direct repair of the popliteus. The patient was seen at 29 months and found to have a stable knee with good ROM and no evidence of premature physeal closure or angular deformity. Goodrich and Ballard[14] reported on a 10-year-old child who was struck by a car, resulting in a tibial-sided PCL avulsion injury that was repaired with nonabsorbable sutures and that was in combination with an ipsilateral femur fracture.

Despite good overall results reported in several case reports or small series, a true understanding of postoperative knee function in pediatric and adolescent patients with significant PCL injuries, both in isolation and in the multiligament-injured knee, is still lacking. Kim et al[26] collected translation measurements by KT-1000 arthrometer (Medmetric Corporation, San Diego, CA) and stress, as well as IKDC and Lysholm scores in 6 patients with isolated tibial-sided PCL avulsions primarily repaired with arthroscopic transtibial suture fixation. Impressively, the mean Lysholm score was 95 (range, 90 to 100). However, although IKDC scores were not provided in the study, 1 of the 6 patients was reported to have an IKDC outcome in the range of a "C" grade, and was unstable enough to require allograft PCL reconstruction as revision surgery. In our series, although the mean Lysholm (80.1) and Pedi-IKDC (81.3) scores at the most recent follow-up bespeak some limitation in knee function,

this is not unexpected, given the range of concurrent injuries sustained. In addition to the multiligament injuries, meniscus tears requiring operative intervention were seen in 60% of knees, and another significant injury, such as patellar dislocation, severe chondral injury, hip dislocation, or tibial plateau fracture, was seen in 53% of patients. Only 2 of 14 patients (14%) in our series had truly "isolated" PCL injuries which could be deemed comparable with those in the series by Kim and colleagues. Notably, the only patient with multiple functional knee scores <70 represented a statistical outlier, which decreased each of the overall mean scores. This was a 16-year-old girl who sustained a knee dislocation with a femoral-sided PCL avulsion, mid-substance ACL tear, an extensive lateral meniscus tear, and impaction-type anterior lateral tibial plateau fracture. Despite technically successful PCL and meniscus repair and ACL reconstruction performed in the subacute period, by age 18, the patient had developed dual compartment degenerative changes, with Pedi-IKDC, Lysholm, and Tegner scores of 53.2, 52.0, and 6, respectively. While substratified analyses are limited by the complexity of injury patterns and the small sample size, Pedi-IKDC scores were significantly lower in patients sustaining knee dislocations, which is not surprising. In those patients who did not dislocate their knee, Pedi-IKDC, Lysholm, and Tegner scores were 87.4, 85.8, and 8.7, respectively, despite the high number of other nonligamentous knee injuries.

The range of interventions pursued in the operative series yielded few complications, and surgery to address PCL injuries in pediatric and adolescent patients appears to be relatively safe. The distal motor weakness seen in 1 patient was determined to be secondary to sciatic nerve injury related to the hip dislocation sustained concurrently with his knee injury. Arthrofibrosis affecting 3 patients was the most notable complication in the series, although it did not appear to influence final outcome scores. All 3 instances of stiffness followed surgeries performed within 2 weeks after the injury, which included 2 primary repairs of femoral-sided avulsions and 1 ORIF of a tibial-sided avulsion fragment. Interestingly, 3 other cases of avulsions that were repaired in the subacute phase of weeks 2 to 10 after injury, rather than in the first 14 days, demonstrated no postoperative stiffness, although outcomes in these patients were not significantly better at long-term follow-up, making conclusions about timing of surgery difficult.

Posterior crucial ligament injuries, although rare in the pediatric and adolescent population, can present with varying injury patterns and in conjunction with complex knee pathology, such as knee dislocations, multiligament injury, and meniscus tears. Partial and isolated PCL tears, usually managed with conservative measures, generally have good outcome scores. Although complete, intrasubstance ligament tears may be more common in adult patients, skeletally immature patients may alternatively suffer avulsion injuries, in which a fragment of either cartilage or bone or both may be pulled off with the ligament, and may occur on either the tibial or femoral side of the ligament. In such cases, arthroscopic primary repair, including physeal-sparing and physeal-respecting techniques in skeletally immature patients, can successfully restore knee stability, even when addressed in the subacute period several weeks after the injury. PCL reconstruction with allograft also restores knee stability, and should be considered if chronic symptoms are refractory to traditional conservative measures. In general, surgery for PCL injuries in pediatric and adolescent patients should be cautiously considered taking into consideration the patient's age, the type of injury, and the postoperative course in a patient with a chronic injury. More comparative research is needed regarding the intricacies of timing and techniques of operative intervention and prudent conservative management.

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