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Original Research

Outcomes of Operative Management of Multi-Ligament Knee Injuries in an Adolescent Population: A Retrospective Case Series

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Abstract

Background: Multi-ligament knee injuries in adolescent patients are rare. The aim of this study was to describe the presentation, surgical management, and patient outcomes following multi-ligament knee injuries in an adolescent cohort.

Methods: A retrospective case series was conducted involving all patients aged ≤18 years who underwent surgery for a multi-ligament knee injury at a single institution between March 2005 and January 2015. Outcome questionnaires were administered, including the pediatric version of the International Knee Documentation Committee (Pedi-IKDC), Lysholm score, Tegner activity scale, and an internal physical activity questionnaire.

Results: Twenty-three knees from 23 patients were included with a mean (SD) age of 16.4 (± 2.3) years at time of injury. In this study, multi-ligament knee injuries in adolescents resulted mainly from sports-related accidents. The most commonly injured structures requiring reconstruction or repair were the anterior cruciate ligament (91%), the medial collateral ligament (57%), posterior cruciate ligament (22%), posterolateral corner (22%), and lateral collateral ligament (15%). Meniscal procedures were performed concurrently in 65% of knees. Examination at final follow-up, occurring at a median of 20.1 months, demonstrated 100% knees could achieve full extension, and 87% could achieve full flexion. Subsequent manipulation under anesthesia and arthroscopic lysis of adhesions was performed in four (17%) knees. Prior to the management of arthrofibrosis, the average range of motion was 13 degrees fixed flexion to

95 degrees flexion, which increased postoperatively to 2 degrees fixed flexion to 120 degrees flexion at a median of 20 months. Questionnaires were returned by 12 patients (52%) at a median of 3.7 years postoperatively. The mean Pedi-IKDC, Lysholm, and Tegner scores were 81.0 ± 18.1, 82.5 ± 15.5, and 8.3, respectively.

Conclusions: The most commonly injured structure requiring reconstruction or repair was the anterior cruciate ligament after multi-ligament knee injury. Patients with multi-ligament knee injuries should be investigated for concomitant meniscal injuries. Patients were generally able to achieve good functional outcomes at short-term follow-up.

Level of Evidence: IV retrospective case series

Key Concepts

- In this study, multi-ligament knee injuries in children and adolescents resulted mainly from sports-related injuries, and a smaller number were related to traffic accidents.
- The most commonly injured structures requiring reconstruction or repair were the anterior cruciate ligament, followed by the medial collateral ligament, posterior cruciate ligament, posterolateral corner, and lateral collateral ligament.
- Meniscal injuries should be investigated in this population, as concomitant meniscal procedures were required in 65% of knees.
- Postoperative functional results following operative management of multi-ligament knee injuries were good at short-term follow-up and return to sport activities was possible.

Introduction

Multi-ligament knee injuries are defined as injuries involving two or more of the knee soft tissue stabilizers, including the anterior cruciate ligament (ACL), the posterior cruciate ligament (PCL), the medial collateral ligament (MCL) and posteromedial corner (PMC), and the lateral collateral ligament (LCL) and posterolateral corner (PLC).[1] Commonly associated with a tibiofemoral joint dislocation, multi-ligament knee injuries typically result from high-energy mechanisms and may be associated with neurovascular injury, fractures, or periarticular soft tissue injury.[2-5] The incidence of multi-ligament knee injuries ranges between 0.02 and 0.20% of all adult orthopaedic injuries, though this may be an underestimation.[1]

Historically, multi-ligament knee injuries resulted in high rates of persistent instability, loss of motion, and poor function or quality of life in adult patients.[6-10] Nonoperative management is typically reserved for patients who may be unfit for surgery, as literature has demonstrated inferior functional and clinical outcomes compared to operative treatment.[1,11,12] However, there remains controversy regarding optimal operative management, such as timing of surgery and surgical techniques that enhance functional outcomes and recovery.[13-21] This may be due to challenges such as cohort heterogeneity with varying presentation and severity and the lack of surgical technique standardization.[5] Furthermore, the relatively low incidence of multi-ligament knee injuries typically results in studies with a low sample size.

With a greater number of children and adolescents participating in sports and activities in which high-energy

injury mechanisms occur, there is growing awareness of the potential for multi-ligament knee injuries and knee dislocation.[22] However, the majority of research has focused on adult cohorts, with few studies evaluating outcomes in pediatric or adolescent patients following a multi-ligament knee injury.[15,23] Treatment options may include allograft or autograft tissue utilization and ligamentous repair or reconstruction. The existing controversy surrounding the timing of surgery, surgical technique, and postoperative protocol is exacerbated by concerns of growth disturbance and arthrofibrosis when considering skeletally immature and young patients.[2-4,6,12-14,24-27] Additionally, pediatric surgical techniques that minimize the risk to the open physis and the risk of arthrofibrosis increase the complexity of operative procedures.

To address the paucity of existing literature, the purpose of this study was to describe the presentation, surgical techniques, and outcomes of multi-ligament knee injuries in a cohort of patients aged 18 years and younger at a single institution.

Materials and Methods

Study Design

Approval was obtained by the Institutional Review Board as a single-center, retrospective case series with patient contact. The institution's electronic medical record was used to identify all patients aged 18 years and younger who underwent surgical treatment of a multi-ligament knee injury at the pediatric tertiary hospital between March 2005 and January 2015. Multi-ligament knee injury was defined as reconstruction or repair of two or more knee ligaments, including ACL, PCL, MCL or PMC, and/or LCL or PLC. Due to the rare nature of this condition, patients who had undergone initial treatment for their multi-ligament knee injury at an outside institution and subsequently presented to the study institution for surgery were included in the analysis if the subsequent procedure included repair or reconstruction of multiple ligaments. Exclusion criteria were congenital ligament deficiency or incompetence. Patients who had undergone staged procedures more than 6 months apart were also excluded to prevent the inclusion of patients who sustained isolated injuries to two structures at differing time points rather than a true multi-ligament knee injury. There were 23 knees from 23 patients who underwent surgical management of a multi-ligament knee injury between March 2005 and July 2015 deemed eligible for inclusion.

Patient Measures

Demographic data were recorded and tabulated from the electronic medical record, including age at time of injury and sex.

Details pertaining to the sustained multi-ligament knee injury were collected, including date and mechanism of injury and any injury-associated complications, such as compartment syndrome, vascular injury, or nerve injury. Surgical details were recorded, including date of surgery, operative technique, and whether the procedures were performed as a single operation or in a staged fashion. Clinical outcomes were collected, including the documented range of motion at final follow-up; however, knee stability examination findings were not collected due to inconsistent retrospective reporting. Any reported complications were collected. Radiographic evaluation was not performed in this study.

Patient Reported Outcomes

All eligible patients were administered a follow-up questionnaire that included questions surrounding physical activity as well as validated clinical outcome measures through the pediatric version of the International Knee Documentation Committee (Pedi-IKDC) form which assesses symptoms, sports activity and knee function,[28,29] the Lysholm score that measures pain, instability, locking, swelling, limp, stair climbing, squatting, and need for support,[30] and the Tegner activity scale to determine the level of activity.[31] This questionnaire was distributed to patients via mail, and additional phone calls were conducted by the authors to discuss the completion of the questionnaires or to clarify questionnaire responses with patients. The questionnaire was distributed and completed by patients at a separate

time to the physical exam performed at final clinical follow-up.

Operative Management

All patients were admitted under the orthopaedic service, and all operations were performed by one of the institution's fellowship-trained pediatric orthopaedic and sports medicine surgeons. The operative technique used for ligament repair or reconstruction was at the discretion of the qualified orthopaedic surgeon and dependent on the skeletal maturity of the patient. The techniques utilized for ACL reconstruction included physeal-sparing reconstruction with iliotibial band autograft, physeal-respecting reconstruction using soft tissue graft and metaphyseal fixation, or transphyseal reconstruction depending on the skeletal age of the patient, which was determined by bone assessment based on preoperative hand radiographs.[32-36] PCL reconstruction techniques included trans-tibial or physeal sparing reconstruction depending on skeletal maturity and the presence of avulsion.[37] Collateral ligament reconstruction or repair was performed in cases of persistent varus or valgus instability. Reconstruction was favored in cases of mid-substance ligament disruption, while primary repair was considered in cases with either a proximal or distal avulsion injury. All-epiphyseal tunnels were used for collateral ligament reconstruction in skeletally immature patients.

Statistical Analysis

Statistical analysis was conducted using Stata version 17 (StataCorp, College Station, TX, USA). Descriptive statistics were used to report basic demographics, surgical patterns, and outcomes of the study cohort. Continuous variables, assuming approximate normality, were summarized by mean and standard deviation; if normality could not be assumed, the variables were summarized by median and interquartile range. Categorical variables were summarized by proportion and percent.

Results

Of the 23 knees from 23 patients included in the study, the mean (SD) age at time of injury was 16.4 (± 2.3) years (range, 7.6–18.2 years), and the majority were male (16/23; 70%) patients. The most common mechanism of injury was sport, occurring in 18 patients (78%), followed by being a pedestrian struck by motorized vehicles in four patients (17%), and one patient was a passenger in a motor vehicle accident (4%). These details are summarized in Table 1. Two patients initially presented with peroneal nerve palsy (8.7%) after a horse-riding injury and soccer injury; however, there were no cases of arterial injury or acute compartment syndrome associated with the inciting event. One patient (4.3%) underwent initial PLC and PCL repair at an outside institution, then underwent ACL and revision PCL

Table 1. Cohort Demographics

Patient characteristics (N=23 patients)	Freq. (%), or mean ± SD (range)
Age at time of injury (years)	16.4 ± 2.3 (7.6-18.2)
Sex (male)	16 (70)
Laterality (left)	12 (52)
Injury mechanism	
Sports activity	17 (78)
Pedestrian hit by motorized vehicle	4 (17)
Passenger in motor vehicle accident	1 (4)

reconstruction with an allograft at the study institution 8 months later.

Operative Management

The pattern of injured structures in each study patient is summarized in Table 2. Temporary management was not recorded, such as requirement for reduction or immobilization methods. The median time interval between multi-ligament knee injury to surgery was 4.1 weeks (range, 2.1–11 weeks). Staged procedures were performed in four cases (17%), with a median of 16.9 weeks (range, 13.3–24 weeks) between the initial and subsequent operations. Patient 4 underwent an open patellar tendon repair, lateral meniscus repair and MCL repair, followed by an ACL reconstruction 13 weeks later. Patient 7 underwent a lateral femoral condyle open reduction and internal fixation procedure, followed by a PCL reconstruction and MCL reconstruction with allograft 16 weeks later. Patient 19 underwent a PLC repair, followed by an ACL reconstruction 14 weeks later. Finally, patient 23 underwent LCL repair and PCL reconstruction followed by an ACL reconstruction 24 weeks later. While evaluation of skeletal maturity was outside the scope of this paper, patient 13 was 8 years of age at time of injury and underwent a physeal-sparing approach.

The most common injury sustained was an ACL tear, with 21 of the 23 knees (87%) requiring an ACL reconstruction (n=20) or repair (n=1). Physeal-sparing ACL reconstruction using an iliotibial band autograft was performed on one knee, while the other 19 knees underwent standard transphyseal ACL reconstruction using a hamstring autograft (n=10), patellar tendon autograft (n=4), Achilles tendon allograft (n=2), hybrid hamstring autograft and allograft (n=1), tibialis anterior allograft (n=1), or tibialis posterior allograft (n=1).

The MCL was repaired or reconstructed in 13 (57%) knees. Most of these cases occurred in conjunction with ACL reconstruction (n=11), and the remaining two occurred in conjunction with PCL reconstruction or repair (n=2). Primary MCL repair with suture anchors was performed in six knees (26%). Achilles allograft reconstruction was performed in three knees (13%), and semimembranosus tenodesis to the medial femoral epicondyle and medial proximal tibia was performed in four knees (17%).

In total, five (22%) knees required reconstruction or repair of the PCL, which included three knees that underwent transtibial reconstruction using an Achilles allograft. Physeal-sparing PCL reconstruction was performed in one knee using soft tissue allograft in conjunction with an all-epiphyseal femoral tunnel and an all-metaphyseal tibial tunnel.[19] One skeletally immature knee with a femoral-sided PCL avulsion underwent primary PCL repair by suturing the free end of the PCL, passing the sutures through small femoral tunnels, and securing the sutures over a bone bridge on the distal femur.[19]

From the cohort, four (15%) patients underwent LCL reconstruction or repair, and eight (35%) underwent PLC reconstruction or repair, including three patients who underwent combined LCL and PLC reconstruction/repair. Anatomic reconstruction using allograft tissue was performed in five knees with LCL and/or PLC injuries. Acute primary repair was performed in four knees using either a suture anchor or a trans-osseous tunnel in the fibular head. Combined allograft reconstruction and suture anchor repair were performed in two knees. One knee that sustained an avulsion fracture of the fibular head was treated with screw fixation of the fracture.

Concurrent meniscal procedures, either meniscal repair or partial meniscectomy, were required for 15/23 (65%) knees. Eight patients (35%) underwent a partial meniscectomy, though the estimated percent of meniscus debrided was not reported in this study. As demonstrated in Table 2, ‘simple’ suture meniscal repair was performed in seven cases (30%), including six utilizing the all-inside repair pattern and one utilizing the outside-in pattern of repair. One knee required

Table 2. Cohort Injury Pattern and Intraoperative Findings[a]

Pt	Age (y)[b]	Sex	Knee	Ligament injury pattern	Reconstruction (Graft)[c]					Meniscal injury		Staged interval (w)
					ACL	PCL	MCL	LCL	PLC	Location	Treatment	
1	17	M	R	ACL, LCL, PLC	Achilles			ITB	*r*	LM	Simple	
2	18	M	R	ACL, MCL	PT		SM			LM	Simple	
3	18	M	L	ACL, PLC	Achilles				TP	MM	Partial	
4	18	M	R	ACL, MCL	*r*		*r*			LM	Partial	13
5	16	F	L	ACL, MCL	HS		*r*					
6	16	F	L	ACL, MCL	PT		SM					
7	15	M	R	PCL, MCL		Achilles	Achilles					16
8	18	M	L	ACL, MCL	PT		SM			MM, LM	Partial	
9	18	F	L	ACL, MCL	HS		*r*			LM	Simple	
10	14	M	L	ACL, LCL, PLC	TA			*r*	*r*	LM	Simple	
11	17	F	L	ACL, LCL	HS			TA				
12	16	M	R	ACL, PCL	HS	*r*				MM	Partial	
13	8	M	R	ACL, PCL, PLC	ITB	Allograft			*r*	MM	Partial	
14	18	M	L	ACL, PLC	HS				*r*			
15	18	M	L	ACL, MCL	PT		*r*					
16	18	M	L	ACL, MCL	HS		Achilles			LM	Partial	
17	16	M	R	PCL, MCL		Achilles	Achilles			MM	Partial	
18	17	F	L	ACL, MCL	HS + ST		*r*			LM	Simple	
19	18	M	R	ACL, PLC	HS				ST			14
20	15	F	R	ACL, MCL	HS		SM			MM	Simple	
21	15	F	R	ACL, PCL, PLC	TP	Achilles			*r*	LM	Partial	
22	17	M	L	ACL, MCL	HS		*r*			MM	Simple	
23	18	M	R	ACL, LCL, PLC	HS			*r*	TA			24

[a]Achilles, Achilles allograft; ACL, anterior cruciate ligament; F, female; HS, hamstring tendon autograft; ITB, iliotibial band autograft; L, left; LCL, lateral collateral ligament; LM, lateral meniscus; M, male; MCL, medial collateral ligament; MM, medial meniscus; Partial, partial meniscectomy; PCL, posterior cruciate ligament; PLC, posterolateral corner; PT, patellar tendon autograft; Pt, patient number; R, right; Simple, simple suture repair; ST, semitendinosus allograft; SM, semimembranosus allograft; TA, tibialis anterior tendon allograft; TP, tibialis posterior tendon allograft; w, weeks; y, years.
[b]Age (years) at time of initial surgery.
[c]r indicates operative repair rather than reconstruction.

fixation of an associated intra-articular fracture of the lateral femoral condyle, while another knee required patellar tendon repair.

Figure 1 shows the preoperative and postoperative imaging of a 7-year-old boy who sustained a knee dislocation as a passenger in a motor vehicle accident and required reconstruction of the ACL and PCL and primary repair of the LCL and PLC.

Postoperative Recovery and Complications

Physical exam at the final clinical follow-up was documented at a median of 20.1 months (range, 9.5–24.2 months) after the initial operation. Full knee extension (defined as less than or equal to five degrees of extension deficit) was achieved in all knees (100%), and full knee flexion (defined as greater than or equal to 130 degrees of flexion) was achieved in 20 out of 23 (87%) knees.

Figure 1. *Imaging findings of the right knee of a 7-year-old boy. (A,B) Preoperative SPAIR T2-weighted sagittal and coronal MRI findings demonstrating complete rupture of the ACL, PCL, and PLC after a knee dislocation sustained as passenger in a motor vehicle accident. (C,D) Postoperative lateral and AP radiographs following physeal-sparing ACL reconstruction using iliotibial band autograft, and physeal sparing PCL reconstruction using soft tissue allograft, and primary PLC repair. (D/E) Lateral and AP knee radiographs 5.5 years following the initial surgery (13 years old). At final clinical follow-up 2 years following surgery, the patient demonstrated full knee extension and 135 degrees of knee flexion, 2-3mm side-to-side variation in ACL laxity on Lachman testing with stable posterior drawer, varus stress, and Dial tests. ACL, anterior cruciate ligament; AP, anteroposterior; PCL, posterior cruciate ligament; PLC, posterolateral corner; MRI, magnetic resonance imaging.*

Two patients (8.7%) required revision operations in the ipsilateral knee. One patient who underwent initial PCL and PLC repair at an outside institution required ACL reconstruction and revision PCL reconstruction with allograft at the study institution due to instability, followed by a partial medial meniscectomy 1 year later. Subsequently, the patient required a second revision ACL reconstruction with LCL and PLC reconstruction at the study institution for instability and dysfunction of knee 1 year following the initial ACL reconstruction. The second patient required reoperation at the study institution for a meniscal re-tear following a new sport-related injury 1 year after the initial operation, which included a meniscal repair.

Arthrofibrosis affected four knees (17%), requiring subsequent manipulation under anesthesia and arthroscopic lysis of adhesions at a median of 5 months (range, 4-10 months). Prior to the manipulation under anesthesia and lysis of adhesions, the average range of motion was 13 degrees fixed flexion (range, full extension to 30 degrees fixed flexion) to 95 degrees flexion (range, 90 to 100 degrees). Postoperatively, patients' range of motion was 2 degrees fixed flexion (range, full extension to 5 degrees fixed flexion) to 120 degrees flexion (range, 100 to 135 degrees) at a median of 20 months (range, 1 to 41 months) postoperative follow-up. Both patients who initially presented with peroneal nerve palsy had persistent symptoms associated with nerve injury at final clinic follow-up. One patient reported numbness over the proximal lateral leg, distal to the fibular head from the initial injury, who required a peroneal nerve neurolysis procedure. The other patient reported sensory deficits and weakness with ankle and great toe dorsiflexion, with a Nerve Conduction Study performed preoperatively and 24 days following injury which was reported as showing evidence of peroneal neuropathy proximal to the fibular head. At final follow-up 2 years postoperatively, the patient had resolved sensory deficits, full power with ankle dorsiflexion, and minor residual great toe dorsiflexion weakness. There were no cases of surgery-associated nerve injury. No patients had clinical evidence of growth disturbance.

Patient-Reported Outcomes

Patient-reported outcome questionnaires were completed and received by 12 (52%) of the 23 patients at a median time of 3.7 years (2.3–6.1 years) following the initial operation and recorded separately to the physical exam at the final clinical follow-up. No patients who returned questionnaires reported reoperation during the follow-up period.

The mean Pedi-IKDC total score was 81.0 ± 18.1 (range, 31.5–97.8). The mean Lysholm total score was 82.5 ± 15.5 (range, 45–100) postoperatively, with the reported grades of "Excellent" (n=2), "Good" (n=5), "Fair" (n=4), and "Poor" (n=1). The mean Tegner Activity Scale score was 8.3 (mode, 9; range, 3–10) postoperatively. Out of the 11 patients who answered the question on return to sport, seven reported returning to sports at a median of 9 months (range, 7–10 months) following their initial operation.

Discussion

This study presents information surrounding the demographics and the operative course of the adolescent cohort who sustained multi-ligament knee injuries and finds that children and adolescents are generally able to regain adequate range of motion at final follow-up and attain satisfactory subjective and objective outcomes measured 3.7 years following surgery. Sports-associated trauma was the most common mechanism for multi-ligament knee injury in the study cohort, accounting for 70% of the patients' presentations. This is consistent with the findings of Fanelli et al., who reported sports-related injuries and motor vehicle accidents as the two most common causes of PCL-based multi-ligament knee injuries in patients aged 18 years and younger.[15] Similar to the literature in adult and pediatric populations, our study demonstrated large injury heterogeneity, with eight different injury patterns. The most common injury pattern was combined ACL and MCL tears, accounting for 45% of the included knees.

Reconstruction of an ACL tear in skeletally immature patients was performed using either a physeal-sparing technique with iliotibial band autograft,

physeal-respecting with soft tissue graft and metaphyseal fixation, or standard transphyseal techniques, as consistent with current evidence.[32-36] Physeal-sparing PCL reconstruction techniques or repair of a femoral-sided avulsion were performed for PCL injuries in patients with significant growth remaining.[37] With the variety of surgical techniques available for skeletally immature and mature patients, operative stabilization of multi-ligament knee injuries can be a safe and viable option in children and adolescents. Meniscal injuries requiring surgical management were seen in 70% of the cohort; as such, care should be taken to evaluate the meniscus on preoperative magnetic resonance imaging and perioperatively.

In the cohort of 12 patients who completed the final follow-up questionnaire, one patient (8.3%) reported dissatisfaction with knee function following multi-ligament reconstruction, stating postoperative physical therapy focused on re-strengthening rather than range of motion. This patient was one of the four patients who suffered from arthrofibrosis and required a manipulation under anesthetic with lysis of adhesions. The final range of motion recorded to be no fixed flexion deformity to 110 degrees flexion, recorded 16 months after surgery for arthrofibrosis. The mean Pedi-IKDC, Lysholm, and Tegner scores were 81, 82.5, and 8.3, respectively. These scores are comparable to Godin et al., who reported scores of 86 and 6 for the Lysholm and Tegner activity scale, respectively, in adolescent patients 2 years after multi-ligament knee injuries requiring operative management.[23] The return to sport rate was calculated as 64% (7 out of 11 patients who completed return to sport questionnaire), with respondents reporting a median time of 9 months (range, 6 to 12 months) to return to sport postoperatively. Saper et al. cited the most common reason for patients to return to sport at a decreased level after revision ACL reconstruction to be fear of re-injury.[38] These results are similar to those reported following primary and revision ACL among pediatric patients.[39] Patients who underwent a primary hamstring tendon autograft ACL reconstruction were reported to have a Pedi-IKDC ranging from 84-90, Lysholm score between 91-92.1, Tegner score of 6.32, and 82-96% of patients reported return to sport.[39-43] Patients who underwent a primary ACL reconstruction utilizing the bone-patella tendon-bone technique were shown to have an average Pedi-IKDC of 86-88, Lysholm of 83.4-87.7, Tegner score of 5-5.5 and return to sport rate at 62-90%.[44-46] Patients who underwent a primary ACL reconstruction using the iliotibial band autograft were found to have a Pedi-IKDC ranging from 93-97.7, Lysholm score between 93-95.7, Tegner score of 8, and return to sport rate of 96%, though this was recorded in a skeletally immature patient.[39,41,47,48] In revision cases reported in the literature, the average Pedi-IKDC score ranges from 77.5-79.7, Lysholm score ranges from 79-93.7, Tegner score ranges from 6-6.9, and return to sport rate is 69%.[33,38,39]

Optimal timing for surgery and whether single or staged procedures should be utilized has been controversial, though most literature involves adult cohorts. With respect to optimal timing for surgery, a systematic review conducted by Vicenti et al. reported patients managed with early surgical treatment had higher functional outcome scores, though no studies involved pediatric patients.[11] However, out of the six included studies, only two demonstrated statistically significant differences in Lysholm score,[14,47,48] and one reported statistically significant differences in postoperative range of motion.[47] In our study, the median duration from injury to surgery was 4 weeks, ranging between 2 weeks and 11 weeks. Indeed, despite the heterogeneity in time to surgery, at the follow-up occurring at a median of 20.1 months postoperatively, 100% of knees demonstrated full extension and 87% demonstrated flexion of at least 130 degrees. Within the literature, there is conflicting evidence between single and staged procedures. Mook et al. reported a higher rate of joint stiffness following single-stage surgery for knee dislocation compared to staged surgery.[41] In comparison, Godin et al. reported functional improvement after single surgery for multi-ligament knee injuries in adolescent patients,[23] and Levy et al. reported no difference in range of motion in single

versus staged multi-ligament knee reconstruction in adult patients.[12] In this study, four cases underwent staged procedures with a median of 15 weeks between the two procedures. One of these cases involved initial fixation of a lateral femoral condyle fracture with MCL repair, with subsequent PCL and MCL reconstructions. Another case required initial patellar tendon, MCL, and lateral meniscus repairs, with a subsequent ACL reconstruction performed 3 months later. Comparisons of outcomes for staged and single operations were unable to be performed, given the small cohort size.

At the time of injury, two patients presented with peroneal nerve palsy (8.7%), and no vascular injuries or cases of compartment syndrome were present in this cohort of young patients. Postoperatively, arthrofibrosis was the most common complication following multi-ligament reconstruction with arthroscopic lysis of adhesions and manipulation under anesthesia to treat arthrofibrosis required in four (17%) patients. These patients regained full range of motion at final follow-up. In contrast, Hanley et al. reported 14% of adult patients required manipulation under anesthesia or lysis of adhesions for postoperative knee stiffness following surgical management of multi-ligament knee injuries.[49] Ellington et al. reported the multi-factorial nature of postoperative stiffness, which may be influenced by intraarticular adhesion formation, graft placement, and timing of surgery.[50] The present study was not powered to compare rates of arthrofibrosis as a function of surgical timing or technique. However, it is interesting to note that four of the five patients who required surgery for arthrofibrosis had undergone reconstruction or repair of the PLC and/or LCL.

There are some limitations of this study. As a retrospective review of surgical management and outcomes associated with multi-ligament knee injuries, the series involves a small, heterogenous cohort without a control group. Knee stability was not collected due to inconsistent reporting; however, this may be considered in future prospective trials as an important clinical outcome. As multi-ligament knee injuries are a rare injury, the decision to include procedures of patients who underwent initial operative management at an outside institution and were referred for ongoing surgical management was accepted, despite increasing the heterogeneity of the cohort. Given the small size and variability in surgical techniques, the study is not sufficiently powered to detect differences between groups or to draw conclusions regarding optimal surgical techniques and timing for each injury pattern. As multi-ligament knee injuries are uncommon, pooling data across institutions may establish sufficient statistical power to overcome these limitations. The questionnaire was distributed to patients via the mail with additional phone calls; however, only 12 completed questionnaires were received for 12 patients. This may introduce response bias. While the biological age of the patients was not considered in this study through radiographic assessment of physis, larger powered studies may evaluate the difference in outcomes across various age categories. Future studies may consider segmentation of clinical and subjective patient-reported outcomes according to injury types to assist in prognostication for this population. Subsequent longer-term investigations should seek to examine the rates and predictive factors associated with progression to osteoarthritis to allow for modification of surgical techniques as required. Effective management remains an important population health consideration, given that the associated morbidity in children with many disability-associated life years ahead is substantial.

In conclusion, multi-ligament knee injuries in adolescents in this study resulted mainly from sports-related injuries, and a smaller number from motor vehicle injuries. Using well-described techniques, multi-ligament knee reconstruction can be performed in skeletally immature patients. Patients were generally able to achieve good functional outcomes at short-term follow-up and return to sport was possible.

Disclaimer

No funding was received. The authors report no conflicts of interest related to this manuscript.

Additional Links

- POSNAcademy: Pediatric ACL Reconstruction Using 7-Stranded Autologous Hamstring
- POSNAcademy: ACL Reconstruction in the Skeletally Immature Patient

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