Outcomes After Single-Stage Anatomic Multiligament Knee Reconstruction With Early Range of Motion in Adolescents

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Background: Multiligament knee injuries (MLKI), rare in adolescents, are challenging injuries that require complex surgical reconstruction. Historically, nonanatomic reconstructions have been associated with prolonged immobilization and failure to restore normal knee biomechanics, resulting in arthrofibrosis and high rates of graft failure.

Purpose: To describe the clinical and patient-reported outcomes (PROs) for adolescent patients treated with single-stage anatomic multiligament knee reconstruction.

Study Design: Case series; Level of evidence, 4.

Methods: A single-center retrospective study was performed of patients ≤18 years old who underwent reconstruction of MLKIs by a single surgeon between 2014 and 2019 using a single-stage anatomic technique, with protected weightbearing and early range of motion. Complications were defined as infection, arthrofibrosis, deep vein thrombosis (DVT) or pulmonary embolus, and secondary surgery. PROs, including the pediatric version of the International Knee Documentation Committee (Pedi-IKDC) and the Tegner activity score, were obtained at a minimum of 2 years postoperatively.

Results: Included were 30 patients (21 male, 9 female; mean age, 15.4 years). The most common ligamentous reconstruction types were anterior cruciate ligament (ACL) + fibular collateral ligament (12 patients; 40%) and ACL + medial collateral ligament (9 patients; 30%). Three patients (10%) had secondary surgeries, including irrigation and debridement of a granuloma, a staged osteochondral allograft transplantation to a lateral femoral condyle impaction fracture, and repair of a medial meniscal tear and lateral femoral condyle fracture associated with new injuries 2 years after ACL + fibular collateral ligament reconstruction. Two patients (7%) developed arthrofibrosis and 1 patient (3%) developed DVT. PRO scores obtained at a mean of 37 months postoperatively included a mean Pedi-IKDC of 87 (range, 52-92) and a median highest Tegner score at any point postoperatively of 9 (range, 5-10). Of the patients who were athletes before their injury, 70% returned to the same or higher level of sport postoperatively.

Conclusion: Reconstruction of MLKI in this series of adolescents with single-stage anatomic techniques and early range of motion resulted in low rates of secondary surgery, few complications, and good knee function as well as PRO scores at mean 3-year follow-up.

Keywords: multiligament knee injury; multiligament knee reconstruction; adolescent; anterior cruciate ligament; medial collateral ligament; fibular collateral ligament; posterolateral corner; outcomes; adolescent

Multiligament knee injuries (MLKI) in adolescents are challenging injuries that require complex surgical reconstruction and lengthy rehabilitation. The complexity of lateral and medial knee anatomy and injury patterns has resulted in a multitude of described reconstruction techniques. Historically, nonanatomic reconstructions and cruciate and collateral repairs as the treatment of MLKI have resulted in failure to restore normal knee biomechanics and high rates of graft failure.[24,29] These reconstructions have also been associated with the need for prolonged immobilization protocols that increase rates of arthrofibrosis.[21,22] Thus, single-stage anatomic reconstructions are preferred to allow for early range of motion (ROM), lower

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rates of graft failure, relatively shorter recoveries, and superior outcomes.[13,15,21]

Compared to isolated anterior cruciate ligament (ACL) injuries, MLKIs account for a smaller proportion of acute knee injuries, particularly among adolescents.[1] Consequently, outcome studies of multiligament reconstruction in this population are limited.[8] The purpose of this study was to describe the clinical outcomes and patient-reported outcomes (PROs) of adolescent patients treated with single-stage anatomic multiligament knee reconstruction.

METHODS

An institutional review board-approved, single-center retrospective review was performed of consecutive patients ≤18 years old who underwent multiligament knee reconstruction by a single surgeon using a single-stage anatomic technique between January 2014 and December 2019, with protected weightbearing and early ROM protocol. Multiligament reconstruction was defined as treatment of a combination of 2 or more of the following: ACL; posterior cruciate ligament (PCL); medial collateral ligament (MCL); and fibular collateral ligament (FCL). Depending on the injury pattern and severity of the lateral knee injury, some or all of the components of the posterolateral corner (PLC), including the popliteus tendon and popliteofibular ligament (PFL), were addressed. Patients with <24 months of follow-up were excluded. Additional exclusion criteria were staged surgery with the index surgery performed outside of the study institution, underlying metabolic bone disease or connective tissue disorder, and incarcerated patients.

Physical examination,[3] magnetic resonance imaging,[6] and validated stress radiographs[12,14] were utilized for diagnosis and to guide treatment. Formal physical therapy and home exercises to achieve terminal knee extension, flexion, and quadriceps function were performed before surgery. Achieving normal or near-normal knee ROM was a prerequisite before proceeding with ligamentous reconstruction. Modifications were made to avoid valgus and varus stress in MCL and FCL injuries, respectively, and to include the use of prone knee flexion in patients with PCL injuries to avoid posterior tibial sag. Patients with MLKI that included MCL injury were typically treated with an initial 4 to 6 weeks in a hinged knee brace after injury to allow for early protected ROM to minimize the risk of postoperative arthrofibrosis. Similarly, PCL injuries were treated in a dynamic PCL-specific brace for 4 to 6 weeks after injury. Again, this bracing occurred concomitantly with physical therapy to restore knee motion. In these patients, valgus and PCL stress radiographs were repeated after a period of 4 to 6 weeks of bracing and physical therapy to assess for residual laxity and need for reconstruction.

The indication for FCL reconstruction was a side-to-side difference of ≥2.2 mm on varus stress radiographs, while a difference of ≥4 mm indicated a need for PLC reconstructions including FCL, popliteus, and PFL componenets.[10,14] Valgus stress radiographs with a side-to-side difference of 3.2 to 9.8 mm indicated a complete superficial MCL tear, while a difference of >9.8 mm indicated a complete tear of all medial knee structures and the need for MCL and posterior oblique ligament reconstructions.[12] Indications for PCL reconstruction included 8 to 11 mm of side-to-side increased posterior translation on stress radiographs.[9]

Surgical Technique

Graft options for adolescent multiligament knee reconstructions are numerous. Our preference for grafts is as follows: ACL reconstruction with quadriceps tendon or bone–patellar tendon–bone autograft; double-bundle PCL reconstruction with Achilles allograft with calcaneus bone block for the anterolateral bundle and tibialis posterior allograft for the posteromedial bundle; isolated FCL reconstruction with semitendinosus autograft; full PLC reconstruction with a split Achilles allograft with calcaneus bone blocks for both the FCL-PFL and popliteus; and MCL reconstruction with semitendinosus autograft or allograft.

Reconstruction of the posterolateral corner was performed as described in detail by Serra Cruz et al[27] and included peroneal nerve neurolysis in all patients. In patients with MLKI with a medial knee injury component that failed to improve with bracing and had increased valgus laxity at 20° of flexion, augmented repair was performed utilizing a semitendinosus autograft with suture anchor or socket fixation at the tibial and femoral attachments.[31] For those medial knee injuries with increased valgus laxity in both flexion and full extension, anatomic MCL and posterior oblique ligament reconstruction was performed.[5] This technique utilizes 2 grafts, 4 separate closed-socket tunnels, and suture anchors to restore the proximal attachment of the superficial MCL. Double-bundle PCL reconstruction was performed, as published by Chahla et al,[4] and utilized a single transtibial tunnel and 2 sockets in the center of the anterolateral and posteromedial bundle footprints.

Postoperative Protocol

Postoperative weightbearing was guided by the concomitant meniscal and chondral procedures performed in

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addition to multiligament knee reconstruction, typically including touch-down weightbearing for 6 weeks in a hinged knee brace locked in extension, 50% weightbearing for week 7, 1 crutch for week 8, and then weightbearing as tolerated. The brace was unlocked to work on early ROM: 0° to 90° for the first 4 weeks, with progression as tolerated. If PCL reconstruction was performed, prone ROM, or supine ROM in a dynamic PCL brace, was then performed to prevent posterior tibial sag and potential stretch of the PCL grafts in the early postoperative period.[19] Aspirin 81 mg twice daily was used for deep vein thrombosis (DVT) prophylaxis in postpubescent patients for 4 weeks postoperatively, at which point patients were typically highly mobile and had returned to school.

A standard structured rehabilitation protocol beginning 2 to 3 days postoperatively was utilized and included ROM, progressive strengthening, proprioception, and ultimately endurance. A running progression was typically initiated at around month 4, with side-to-side motions limited until 6 months. Functional testing guided the initiation of a return-to-play progression, with full return to play no sooner than 9 months for ACL + collateral ligament reconstruction and 12 months for knee dislocations requiring bicruciate ± collateral ligament reconstruction.

Data Collection

Patient demographics, mechanism of injury, ligamentous injury patterns, surgical treatment, outcomes, and complications were gathered from chart review. Complications were defined as infection, arthrofibrosis, DVT or pulmonary embolus (PE), and secondary surgery. Arthrofibrosis was defined as the lack of $\geq 10°$ of flexion compared with the contralateral knee and inability to achieve 0° of extension. PROs, including the pediatric version of the International Knee Documentation Committee (Pedi-IKDC) and the Tegner activity score, were obtained via telephone call a minimum of 2 years postoperatively.

RESULTS

A total of 39 patients met the inclusion criteria, 9 of whom were excluded for the following reasons: <24 months of follow-up (n = 5); staged surgery with index procedure performed outside of the study institution (n = 2); metabolic bone disease (n = 1); and patient incarcerated (n = 1). Among the final cohort of 30 patients, the mean age was 15.4 ± 1.6 years old (range, 12-18 years old), and the mean body mass index was 24.9 ± 5.2 kg/m^2 (range, 17.9-41.6 kg/m^2). There were 21 (70%) male patients and 9 (30%) female patients. Six patients (20%) had open physes, all of whom had less than 2 years of growth remaining as calculated by hand bone age. The most common mechanism of injury was team sports (24 patients; 80%), followed by injuries secondary to a trampoline (2 patients; 7%), fall (1 patients; 3%), gymnastics (1 patient; 3%), wrestling (1 patient; 3%), and dirt bike crash (1 patient; 3%). Six patients (15%) sustained a knee dislocation. Ligamentous reconstruction patterns are listed in Table 1. All patients underwent a single surgery for their multiligament reconstruction, and the median time from injury to surgery was 56 days (range, 9-146 days).

TABLE 1
Patients According to Ligamentous Reconstruction Type (N = 30 Patients)[a]

Reconstruction Type	n
ACL + MCL	9
ACL + FCL	12
ACL + FCL + POP + PFL	3
ACL + MCL + FCL	1[b]
ACL + PCL + MCL	1[b]
ACL + PCL + FCL	1[b]
PCL + FCL + POP + PFL	2[b]
ACL + PCL + MCL + FCL + POP + PFL	1[b]

[a]ACL, anterior cruciate ligament; FCL, fibular collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament; PFL, popliteofibular ligament; POP, popliteus tendon.
[b]Knee dislocation.

One patient, a 16-year-old boy with a traumatic knee dislocation and ACL, PCL, and posterolateral corner injury, had a concomitant complete peroneal nerve palsy at the time of injury. There were no acute vascular injuries. A total of 12 (40%) patients had a meniscus injury requiring treatment at the time of ligamentous reconstruction, with 7 of these patients treated with meniscus repair. Of these 12 patients, 8 patients had a lateral meniscal tear (including 1 posterior root avulsion and 1 complete radial tear), 1 patient had a medial meniscal posterior root tear, and 3 patients had combined medial and lateral meniscal tears.

There was 1 intraoperative complication, which was a sidewall injury to the peroneal vein in an 18-year-old male patient who underwent ACL, FCL, and PLC reconstructions. This was treated with peroneal vein ligation after consultation with vascular surgery. The patient had no postoperative sequelae related to this.

Patient-Reported Outcome Scores

PRO scores were obtained in all patients at a mean of 37 months postoperatively (range, 24-81 months). The mean Pedi-IKDC score was 87 ± 8.9 (range, 52-92). The median preinjury Tegner score was 9 (range, 3-9), the median highest Tegner score at any point after surgery was 9 (range, 5-10), and the median Tegner score at final follow-up was 7 (range, 4-10). With the exception of 3 patients who were not involved in athletics before their injury, all patients returned to sports. Of the 27 patients who returned to sports, 19 (70%) returned to the same level or higher. Of the 8 patients who did not return to the same level of sport, 6 (75%) completed high school in the year after their injury and had not intended to play collegiate sports. One patient, a 14-year-old gymnast at the time of

her ACL-MCL injury, elected not to pursue gymnastics after missing a year at the elite level and transitioned to track and cheer. The final was the 14-year-old male patient previously described with an ACL graft tear who transitioned from competitive to recreational basketball.

Complications

There were 5 secondary surgeries among 3 patients. One patient, a 14-year-old boy who underwent ACL and FCL reconstructions with lateral capsular repair, developed a granuloma over the medial proximal tibial incision 3 months postoperatively that did not heal with local wound care. He had an irrigation and debridement, removal of the ACL tibial fixation, and revision wound closure 7 months postoperatively. This same patient sustained a new injury playing basketball 20 months after his index procedure and represented the single patient (3%) with graft injury. He was treated with revision ACL reconstruction. A second patient, a 15-year-old boy, sustained a large depressed lateral femoral condyle impaction fracture in association with ACL and MCL injuries. He was treated with a planned staged 20-mm osteochondral allograft transplantation 6 months after multiligament reconstruction. The third patient was a 13-year-old girl with ACL and FCL reconstructions who sustained a new injury and bucket-handle medial meniscal tear while playing basketball 22 months after her index surgery and was treated with medial meniscus repair. She returned to sports after her meniscus repair and then had a subsequent injury with resultant coronal plane fracture of the lateral femoral condyle treated with open reduction and internal fixation 7 months later. She was found to be vitamin D deficient with a 25(OH)-vitamin D level of 14 ng/mL at the time of her fracture. Her vitamin D was supplemented to achieve normal levels, her fracture healed, and she had returned to full sports at the most recent follow-up 4 years after her multiligament knee reconstruction.

Arthrofibrosis was identified in 2 (7%) patients over the course of a 16-month clinical follow-up. First was the 16-year-old male patient with a concomitant peroneal nerve injury whose final terminal flexion was 120° compared to 135° on the contralateral knee. This patient was offered arthroscopic lysis of adhesions and manipulation but declined further treatment, having returned to basketball without functional limitations. Second was a 17-year-old male patient who underwent ACL-PLC reconstruction and was lacking 3° of terminal extension but had full knee flexion. He was not an athlete, did not feel that he had functional limitations, and did not want to pursue any additional treatment. No patients required manipulation under anesthesia or lysis of adhesions. One patient developed a popliteal vein DVT postoperatively and was treated uneventfully with enoxaparin. There were no PEs. The single patient with the complete peroneal nerve palsy initially used an ankle-foot orthosis postoperatively. He ultimately had partial nerve recovery (4/5 strength with testing of the extensor hallucis longus and extensor digitorum longus in toes 2-4, intact but diminished sensation to light touch in the first web space and dorsum of the foot) at the time of the final follow-up of 34 months. He returned to playing basketball recreationally and elected not to use any orthosis as he had adequate dorsiflexion strength. No patient was noted to have cruciate nor collateral graft laxity at the time of final clinical examination at a mean of 16 months postoperatively.

DISCUSSION

Multiligament knee reconstruction in this series of adolescents with single-stage anatomic techniques and early ROM resulted in low rates of secondary surgery, few complications, and good knee function and PROs at an average follow-up of 3 years. Despite the severity of MLKI and high rates of reported complications, the positive outcomes identified in this adolescent population further validate findings by other authors that younger patients experience superior outcomes compared to older adults.[8,23] Godin et al[8] described 20 adolescents with MLKI treated with single-stage anatomic reconstruction, highlighting significant improvements in PROs from pre- to postoperatively and excellent satisfaction. Furthermore, Levy et al,[23] in a series of 125 MLKI treated with reconstruction, identified age <30 years as an independent predictor of improved IKDC and Lysholm scores. The majority of patients in the current series, in addition to these prior studies, were 2-ligamentous injuries, which may have influenced the superior outcomes compared with patients with knee dislocations.

Anatomic multiligament knee reconstruction techniques allow for reproduction of native knee biomechanics as well as for early knee ROM without compromising graft integrity.[11,16,20] All patients in this series were treated with biomechanically validated reconstruction techniques.[16,20,28] Early knee ROM with these techniques has proven to decrease rates of arthrofibrosis and subsequent surgery,[7,13,25] a finding confirmed by this current study in adolescents. The biomechanical function of the cruciate and collateral ligaments is interconnected, and their integrity is critical for optimal knee function.[17,18,26,30] Staged ligament surgery not only increases the number of anesthetic exposures and lengthens the patient's postoperative rehabilitation but also risks the reconstructed grafts stretching out due to nonphysiologic loading in the absence of secondary stabilizers. An additional benefit of a single-stage reconstructive procedure unique to adolescents is the reduced impact on time away from school.

Primary ligament repair is a treatment option that should be reserved for very select injuries, most notably acute avulsion injuries within the first 3 weeks after injury.[7] In the pediatric population, repair may be considered for acute bony avulsions without midsubstance tearing or attenuation. Otherwise, numerous studies have illustrated inferior repair outcomes compared to reconstruction, particularly of the posterolateral corner, as it is less likely to restore native knee stability and results in higher rates of failure.[2,7,15,21,31]

Historically, early surgical treatment has been shown to result in higher outcome scores and sports activity scores compared to delayed treatment.[22] Multiple factors, however, can impact surgical timing, including concomitant neurovascular injuries, avulsion injuries amenable to early repair, and MCL and PCL injuries treated with an initial phase of bracing. In reality, the authors feel that performing a single-stage anatomic reconstruction after achieving near normal preoperative ROM, as was done in this case series at a median of 8 weeks, is likely more critical to optimal outcomes than reconstruction within a specific timeframe.

The rate of arthrofibrosis after MLKI reconstruction in adolescents was found to be 3% in this series, which is lower than has been reported for MLKI in adult populations.[13] We believe the greatest contributors to this low rate is achieving normal or near normal preoperative motion; anatomic reconstructions to permit early postoperative ROM; use of physical therapists experienced in achieving early motion, motivated athletic patients; and patient and family education on the importance of early terminal knee extension and progressive flexion.

All patients in this series who had FCL reconstruction, with or without PLC reconstruction, underwent peroneal nerve neurolysis. This is a critical initial step in posterolateral reconstruction and is done to allow for safe drilling of an anatomic FCL tunnel in the fibula and minimize the risk of peroneal nerve neurapraxia postoperatively. The neurolysis extends from posteromedial to the long head of biceps proximally to the peroneal fascia distally, extending a few millimeters into the peroneal fascia to avoid compression of the nerve at this level in the setting of postoperative swelling. In patients with a preoperative peroneal nerve palsy, including 1 patient in this series, and significant posterolateral corner injury, the peroneal nerve is typically in continuity but can be significantly enlarged and encased in adhesions. In these patients, meticulous peroneal nerve neurolysis and decompression can be followed by a nerve wrap to prevent further adhesions and compression. Aside from the single patient with a preoperative peroneal nerve palsy, no patient in this series with FCL and PLC reconstruction developed a postoperative peroneal nerve palsy.

In those patients with a peroneal nerve palsy, serial examinations should be performed to monitor for changes in motor and sensory function. The most distal extent of a Tinel's sign over the peroneal nerve can be monitored in reference to the distance from the fibular head to gauge nerve recovery. In the absence of nerve recovery, an electromyography and nerve conduction study can be performed to assess for signs of electrical response. Patients should be encouraged to perform stretching of the gastrocsoleus complex to prevent an equinus contracture, and the use of an ankle-foot orthosis aids in ambulation.

Limitations

This study is not without limitations. Compared to isolated ACL reconstruction, MLKI occurs at a significantly lower frequency. As a result, the study cohort was relatively small and injury patterns were diverse. This is, however, a larger series compared to the only previously published isolated adolescent cohort.[8] No preinjury PROs, aside from self-reported Tegner score before injury, were available on the patient population, and therefore, changes in preinjury to postinjury knee function could not be determined. Postoperative stress radiographs and instrumented knee laxity were not routinely obtained, and assessment of postoperative knee stability was therefore based on the physician's clinical exam. Radiographs were routinely obtained 2 to 3 weeks and 1 year postoperatively in skeletally immature patients, but they were not routinely repeated unless there was clinical concern for new injury. Thus, this study was not designed to assess for radiographic changes of arthritis, and longer-term follow-up is necessary to determine whether this finding in select adults after MLKI occurs similarly in the adolescent population.

CONCLUSION

Reconstruction of MLKI in this series of adolescents with single-stage anatomic techniques and early ROM resulted in low rates of secondary surgery, few complications, and good knee function and PROs at average 3-year follow-up.

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