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Single-Stage Multiple-Ligament Knee Reconstructions for Sports-Related Injuries

Outcomes in 194 Patients

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Background: Outcomes after sports-related multiple-ligament knee reconstructions are limited.

Purpose: To evaluate outcomes after single-stage surgical treatment of sports-related multiple-ligament knee injuries and to compare outcomes after anterior cruciate ligament (ACL)–based and posterior cruciate ligament (PCL)–based multiple-ligament knee reconstructions.

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

Methods: Skeletally mature patients with at least 2 major knee ligaments torn during a sporting activity that required surgery with a minimum of 2 years' follow-up were included. The Lysholm score, Tegner activity scale, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and 12-Item Short Form Health Survey Physical Component Summary were collected preoperatively and at a minimum of 2 years' follow-up. Clinical data, including range of motion and knee stability, were also recorded at final follow-up.

Results: A total of 276 patients with multiple-ligament knee injuries incurred during sport participation from 2010 to 2016 were identified. Of the 276 patients, 194 (70.5%) had complete follow-up at a mean 3.5 years (range, 2-8 years). There was a significant improvement in all outcome scores as compared with the preoperative scores ($P < .001$ for all scores). The median (first and third quartiles) Tegner activity score improved from 1 (0, 2) preoperatively to 6 (4, 7) postoperatively. Significant improvements were from 41 (22, 57) to 90 (78, 95) and 44 (24, 60) to 3 (1, 8) for median Lysholm and WOMAC scores, respectively. There was no significant difference in postoperative outcome scores between patients treated in the acute and chronic phases. Furthermore, there was no significant difference between PCL- and ACL-based multiple-ligament knee injuries. Eighteen (9.3%) patients developed arthrofibrosis requiring reintervention surgery.

Conclusion: These results demonstrated that single-stage anatomic-based knee ligament reconstructions with immediate postoperative rehabilitation in the setting of sports-related multiligament injuries yielded significantly improved outcomes irrespective of the ligament injury pattern. In addition, there was no difference in outcomes between ACL- and PCL-based injuries in the setting of sports-related multiligament injuries.

Keywords: multiligament injury; anatomic; reconstruction; stress radiographs; knee dislocation

Multiligament knee injuries are potentially devastating injuries that commonly affect a young and active population.[36] The reported outcomes of multiligament knee injuries consist of small cohort studies with heterogeneous patient populations. Furthermore, most multiple-ligament injury studies include patients with knee dislocations[6,8,40] from both low- and high-energy injury mechanisms. Knee dislocations are commonly defined as bicruciate knee ligament injuries with or without injuries to the collateral ligaments. However, the energy involved, the magnitude of soft tissue injury, and the risk of concomitant neurovascular injuries are highly variable according to the pattern of ligament injury.[47] Therefore, it is important to distinguish between multiligament knee injuries that occur with and without concurrent knee dislocation.[37] Outcomes on lower-velocity sports-related multiple-ligament injuries, not caused by knee dislocations, are still lacking.

A systematic and comprehensive evaluation of all torn knee structures and the soft tissue status is fundamental for surgical planning and a subsequent successful outcome. In this regard, the timing of surgery, treatment method

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(operative vs nonoperative, repair vs reconstruction), availability of grafts, and postoperative rehabilitation program are some of the factors that have to be considered in the decision making. The current body of literature demonstrates inconsistent functional results and return to sports and work in 53% and 88% of patients, respectively.[7] This could be attributed to multiple factors, such as (1) incorrect/incomplete diagnosis and staged procedures, which can overload the reconstruction grafts and jeopardize the index surgery; (2) nonanatomic techniques that do not reproduce the native biomechanics; and (3) the improper or incorrect timing of postoperative rehabilitation protocols.

The purpose of this study was to evaluate outcomes after single-stage surgical treatment of sports-related multiligament injuries treated with biomechanically validated anatomic-based reconstructions and an immediate postoperative rehabilitation program emphasizing knee motion on postoperative day 1. Additionally, we compared outcomes after anterior cruciate ligament (ACL)–based and posterior cruciate ligament (PCL)–based multiple-ligament knee reconstructions. The hypotheses were that single-stage anatomic reconstructions would lead to improved postoperative outcomes with low complication rates and that ACL- and PCL-based multiple-ligament knee injuries would have comparable outcomes after anatomic-based reconstructions and early postoperative rehabilitation.

METHODS

Patient Population

This study was approved by the Vail Health institutional review board (#2018-22). Patients surgically treated for multiligament knee injuries from May 2010 to September 2016 by a single surgeon (R.F.L.) were identified. Patients were required to have at least 2 of the 4 major knee ligaments (ACL, PCL, superficial medial collateral ligament [MCL], or fibular (lateral) collateral ligament [FCL]) or the popliteus torn and requiring surgery, be skeletally mature, have sustained a sports-related injury, and have a minimum of 2 years of follow-up. There was no specific upper age for the patients, and a decision was made with the senior surgeon (R.F.L.) based on the patient's age, activity levels, and any associated medical comorbidities. Exclusion criteria included previous knee injury or surgery, concomitant ipsilateral knee intra-articular fracture, skeletal immaturity, and non–sports related mechanism of injury.

Demographics, Injury Characteristics, and Patient Evaluation

Patient information included sex, age, and specific ligament injury pattern. Patients were defined to have an acute injury if they underwent multiligament reconstruction surgery within 6 weeks of their injury.[10] The mechanism of each patient's injury was classified by sport type (Table 1). Preoperatively, all patients had a complete knee examination, plain and stress radiographs (posterior, varus, and/or valgus as needed),[15,21,25] and a magnetic resonance imaging scan (Figure 1). The type of surgery and the associated graft type were dictated by the presenting pathology, and previously reported anatomic surgical techniques were utilized.[††] Concomitant chondral and meniscal pathology were documented at the time of surgery. Finally, clinical data, including flexion, extension, and patient-reported knee stability, were recorded at final follow-up. Patients were indicated for surgery if they had a grade 3 ACL, PCL, FCL, or posterolateral corner (PLC) injury or a grade 3 MCL tear that had 3+ gapping to valgus stress in full extension at presentation or 3+ valgus gapping to valgus stress at 20° after 4 to 6 weeks of rehabilitation.

Patient Subjective Outcomes

Patients completed a subjective outcome questionnaire preoperatively and at a minimum of 2 years postoperatively, which included the Lysholm score, Tegner activity scale, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), 12-Item Short Form Health Survey (SF-12) Physical Component Summary (PCS), and patient satisfaction with outcome (rated on a 10-point scale: 1 = highly unsatisfied, 10 = highly satisfied). All patients had clinical follow-up with stress radiographs at least 12 months after surgery (mean: 2.0 years, range: 12 months–8 years).

Surgical Management

Anatomic-based reconstructions were performed to reconstruct the torn ligaments as previously described.[††] Complete ligament tears of the main static knee stabilizers were reconstructed, while capsular avulsions or hamstring

[††]References 4, 12, 20, 22, 24, 31, 32, 44, 46.

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TABLE 1
Descriptive Demographics of the Cohort With Sports-Related, Low-Velocity Multiligament Injuries and Minimum 2-Year Follow-up[a]

Injured Ligament Structures	Patients, n	Mean Age at Surgery, y (Range)	Female: Male, n	Mean BMI (Range)	Acute: Chronic, n	Median Time to Surgery, d (Range)	Sports Type, Ball Sport: Ski: Other,[b] n	Chondral Defect, No: Yes, n	Meniscal Lesion, No: Yes, n	Mean Follow-up, y (Range)
ACL/MCL	50	37 (16-65)	24: 26	23.7 (18.8-34.0)	41: 9	15 (1-130)	8: 39: 3	30: 20	17: 33	3.8 (2-7)
ACL/FCL	76	32 (13-69)	40: 36	24.6 (19.4-34.2)	58: 18	13 (1-380)	23: 39: 14	54: 22	37: 39	3.2 (2-8)
ACL/MCL/FCL	14	37 (19-52)	4: 10	26.2 (20.9-31.6)	11: 3	6 (1-243)	1: 11: 2	9: 5	1: 13	3.2 (2-5)
PCL/MCL	13	41 (18-66)	2: 11	25.6 (21.1-33.9)	9: 4	24 (2-392)	2: 6: 5	10: 3	11: 2	3.9 (2-5)
PCL/FCL	9	24 (18-234)	2: 7	22.4 (19.2-26.1)	5: 4	21 (11-522)	2: 3: 4	8: 1	6: 3	3.3 (2-7)
ACL/PCL/FCL	6	31 (16-52)	2: 4	23.2 (20.6-27.3)	5: 1	26 (7-272)	1: 2: 3	3: 3	4: 2	2.7 (2-3)
ACL/PCL/MCL	16	36 (16-464)	6: 10	24.7 (20.4-31.0)	16: 0	12 (1-42)	2: 12: 2	15: 1	7: 9	3.8 (2-7)
ACL/PCL/MCL/FCL	5	32 (21-55)	1: 4	25.8 (23.7-29.2)	4: 1	23 (2-2178)	0: 3: 2	4: 1	0: 5	2.8 (2-4)
MCL/PCL/FCL	1	43	0: 1	NA	1: 0	2	1: 0: 0	0: 1	1: 0	5
Other[c]	4	30 (18-51)	2: 2	21.7 (18.6-23.0)	3: 1	28 (5-353)	1: 3: 0	2: 2	3: 1	5.4 (2-7)
Entire study cohort	194	34.5 (13.6-69.6)	83: 111	24.4 (18.6-34.2)	153: 41	15 (1-522)	40: 119: 35	135: 59	87: 107	3.5 (2-8)

[a]ACL, anterior cruciate ligament; BMI, body mass index; FCL, fibular collateral ligament; MCL, medial collateral ligament; NA, not applicable; PCL, posterior cruciate ligament; PLC, posterolateral corner; PLT, popliteus tendon.
[b]Sports injuries classified as "other" included water skiing, trampoline, and skating.
[c]Other cases: 1 PCL/PLC, 1 ACL/PLT, 2 PCL/PLT.

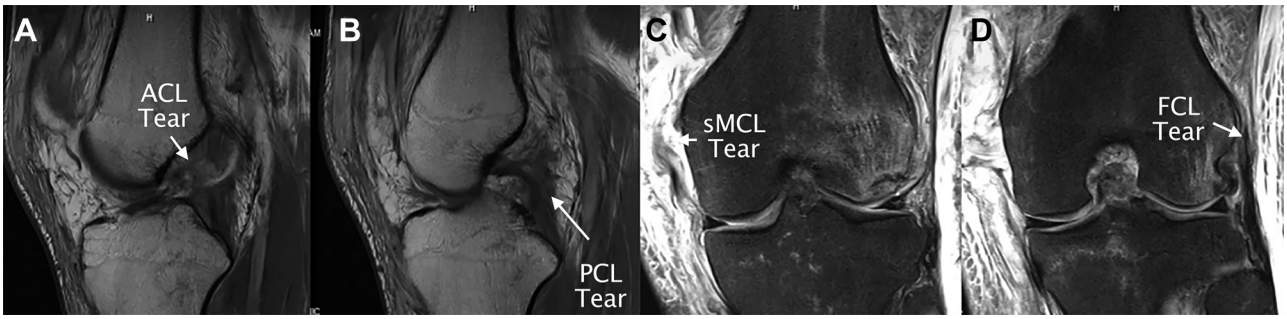

Figure 1. Preoperative MRI series of multiligament injury of the left knee in a single patient. T2-weighted sagittal MRI demonstrates (A) an ACL tear and (B) a PCL tear. (C) T2-weighted coronal MRI demonstrates a superficial MCL tear. (D) T2-coronal MRI demonstrates a proximal FCL tear. ACL, anterior cruciate ligament; FCL, fibular collateral ligament; MRI, magnetic resonance imaging; PCL, posterior cruciate ligament; sMCL, superficial medial collateral ligament.

tendon avulsions were repaired.[10] ACL tears were preferably reconstructed with a bone–patellar tendon–bone autograft[2] or allograft according to age (>55 years) or if the patellar tendon had intrasubstance tear changes on the magnetic resonance imaging scan. All PCL tears had an anatomic double-bundle PCL reconstruction with an Achilles tendon allograft for the anterolateral bundle and a tibialis anterior allograft for the posteromedial bundle.[3] Tears of the MCL were reconstructed with a hamstring tendon autograft.[34] FCL tears were reconstructed with a semitendinosus autograft or allograft, while a complete anatomic PLC reconstruction was performed with a split Achilles tendon allograft.[26,31] The sequence of graft fixation depended on the involved ligament reconstructions. When the PCL was reconstructed, the anterolateral bundle was fixed first at 90° to restore the normal tibiofemoral step-off, followed by the posteromedial bundle with the knee in extension and neutral rotation.[17] In patients with an FCL or complete PLC reconstruction, the FCL or PLC reconstruction grafts were fixed after the PCL but before the ACL and the posteromedial corner structures.[48] The FCL was fixed at 20° of knee flexion and with a slight valgus force and in neutral rotation, followed by the popliteal tendon and popliteofibular ligament at 60° of knee flexion and neutral rotation. The ACL was fixed in full extension, and the posteromedial corner was always fixed last, with the MCL fixed at 20° and the posterior oblique ligament repaired or reconstructed at 0° and in neutral rotation (Figure 2).

Rehabilitation

After surgery, all patients had the same acute rehabilitation goals of protecting the surgical reconstructions and restoring normal joint range of motion (ROM). Regardless of the combination of reconstructed ligaments, all patients were allowed knee motion of 0° to 90° on postoperative day 1 and were nonweightbearing for 6 weeks, followed by a 2-week period in which patients weaned off crutches before achieving full weightbearing at approximately 8 weeks. ACL-based reconstructions were braced in a knee immobilizer for 6 weeks and then transitioned to a hinged knee brace for daily activities. PCL-based reconstructions were

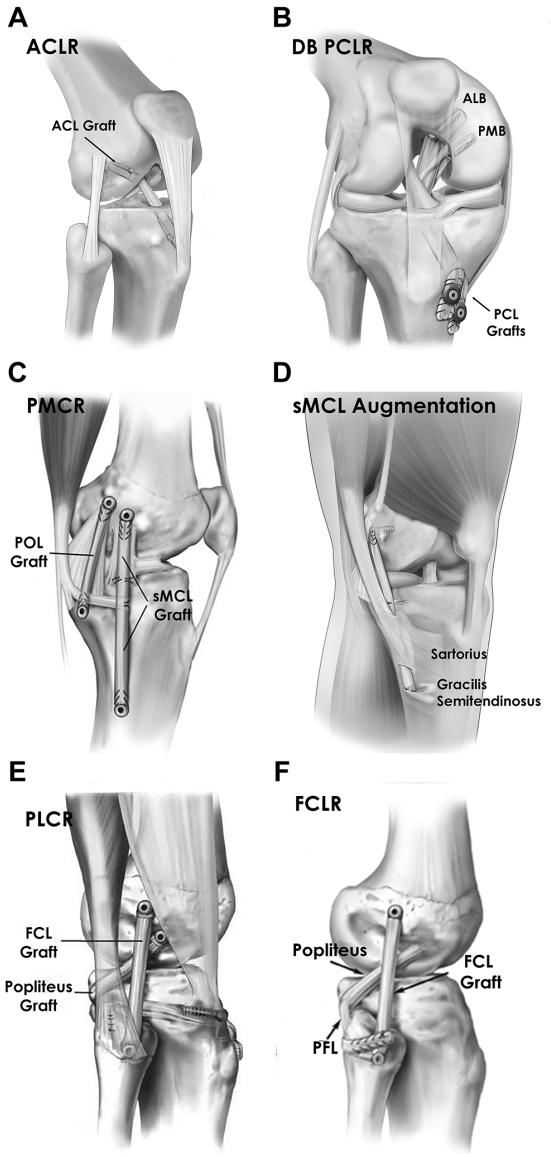

Figure 2. Reconstruction techniques used for multiligament knee reconstruction. (A) Anterolateral view of a right knee shows a single-bundle ACL reconstruction with a patellar tendon graft. (B) Double-bundle PCL reconstruction on a right knee with allografts for the anterolateral and posteromedial bundles. The grafts were fixed on the tibia with interference screws and washers.[17] (C) A complete medial knee reconstruction (left knee).[5] (D) An sMCL augmentation with gracilis and semitendinosus autograft on a left knee. (E) A full posterolateral knee reconstruction. (F) FCL reconstruction on a right knee.[27] ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; ALB, anterolateral bundle; DB, double bundle; FCL, fibular collateral ligament; FCLR, fibular collateral ligament reconstruction; PCL, posterior cruciate ligament; PCLR, posterior cruciate ligament reconstruction; PFL, popliteofibular ligament; PLCR, posterolateral corner reconstruction; PMB, posteromedial bundle; PMCR, posteromedial corner reconstruction; POL, posterior oblique ligament; sMCL, superficial medial collateral ligament.

TABLE 2
Pre- and Postoperative Outcome Scores for the Entire Sports-Related Multiligament Reconstruction Cohort (N = 194) at a Mean 3.5 Years Postoperatively[a]

	Preoperative Score	Postoperative Score	*P* Value
Tegner Activity Scale	1 [0, 2]	6 [4, 7]	<.001
Lysholm	41 [22, 57]	90 [78, 95]	<.001
WOMAC total	44 [24, 60]	3 [1, 8]	<.001
SF-12 PCS	33 [28, 42]	56 [49, 58]	<.001
Patient satisfaction	NA	9 [7, 10]	NA

[a]Values are presented as median [first and third quartiles]. NA, not applicable; SF-12 PCS, 12-Item Short Form Health Survey Physical Component Summary; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

initially placed in an immobilizer and then progressed to a dynamic PCL brace[30] as soon as the swelling allowed for the brace to be worn. The dynamic PCL brace was worn for 6 months postoperatively.

Once patients had weaned off crutches and were able to tolerate 20 minutes of walking, a weightbearing strength program was initiated. This program was customized to each patient's needs but included common periodized phases of muscular endurance, strength, and power development. Each phase was afforded at least 6 weeks to allow for physiological adaptation to the exercise stimulus. Rehabilitation progress was assessed throughout the recovery, with clearance to return to activities provided once patients had achieved a quadriceps index >90% and a passing grade on a functional sports test.

Statistical Analysis

All subgroup comparisons of subjective outcome scores utilized the Mann-Whitney *U* test or Kruskal-Wallis analysis of variance with post hoc pairwise Nemenyi tests. Comparisons between pre- and postoperative time points used the Wilcoxon signed-rank test. Fisher exact test was used to assess associations between binary variables. Unless otherwise noted, data were reported as median (first and third quartiles) and mean ± SD. The statistical programming language R (v 3.5.0) was used for all analyses.[41]

RESULTS

Cohort Demographics and Patient-Reported Outcomes

Of the 276 patients identified, 194 (70.5%) had a minimum 2-year follow-up. Males were significantly more likely than females to be lost to follow-up ($\chi^2[1] = 5.3$, $P = .022$), but no other patient demographics, injury patterns, or baseline patient-reported outcomes were significantly different between the follow-up and lost-to-follow-up groups.

TABLE 3
Pre- and Postoperative Outcome Scores Comparing Acute and Chronic Reconstruction Groups[a]

	Preoperative Score			Postoperative Score		
	Acute	Chronic	*P* Value	Acute	Chronic	*P* Value
n	126	35		153	41	
SF-12 PCS	32 [27, 40]	36 [32, 46]	.017	56 [51, 58]	54 [46, 58]	.077
WOMAC total	48 [31, 64]	24 [14, 40]	<.001[b]	3 [1, 8]	3 [0, 7]	.682
Tegner Activity Scale	1 [0, 2]	1 [0, 3]	.190	6 [4, 7]	5 [3, 7]	.086
Lysholm	37 [20, 54]	57 [39, 0]	<.001[b]	90 [80, 95]	90 [71,95]	.268
Patient satisfaction	NA	NA	NA	9 [7, 10]	8 [7, 10]	.414

[a]Values are presented as median [first and third quartiles]. Not all patients had preoperative scores available. NA, not applicable; SF-12 PCS, 12-Item Short Form Health Survey Physical Component Summary; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
[b]$P < .05$.

TABLE 4
Pre- and Postoperative Outcome Scores Comparing ACL-, PCL-, and ACL + PCL–Based Injury Groups[a]

	Preoperative Score				Postoperative Score			
	ACL (n = 117)	PCL (n = 22)	ACL + PCL (n = 22)	*P* Value	ACL (n = 141)	PCL (n = 27)	ACL + PCL (n = 26)	*P* Value
SF-12 PCS	33 [28, 43]	35 [30, 38]	31 [27, 35]	.344	56 [48, 58]	57 [55, 58]	57 [53, 58]	.236
WOMAC total	43 [24, 59]	32 [18, 44]	63 [53, 77]	<.001[b]	3 [1, 8]	0 [0, 3]	2 [0, 4]	.277
Tegner Activity Scale	1 [0, 2]	1 [0, 2]	1 [0, 3]	.983	4 [2, 6]	4 [1, 6]	4 [2, 6]	.917
Lysholm	41 [25, 58]	45 [40, 63]	18 [13, 39]	.005[b]	90 [77, 95]	91 [84, 96]	85 [79, 94]	.400
Patient satisfaction	NA	NA	NA	NA	9 [7, 10]	8 [3, 10]	9 [8, 10]	.041[b]

[a]Values are presented as median [first and third quartiles]. *P* values calculated via Kruskal-Wallis test. Not all patients had preoperative scores available. ACL, anterior cruciate ligament; NA, not applicable; PCL, posterior cruciate ligament; SF-12 PCS, 12-Item Short Form Health Survey Physical Component Summary; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
[b]$P < .05$.

Among the 194 patients in the follow-up group, there were 111 males and 83 females. The mean age at surgery was 34.5 ± 13.6 years, and the mean follow-up time was 3.5 ± 1.3 years. Concomitant chondral defect and meniscal lesion were found in 59 (30.4%) and 107 (55.2%) knees, respectively. There was no correlation between the presence of a meniscal tear and the presence of a chondral defect. Peroneal nerve injury was found in 4 (3.1%) patients; no patients sustained a vascular injury. Table 1 presents detailed patient demographics and the injury pattern distribution.

At a mean follow-up of 3.5 years, there was a significant improvement in all outcome scores as compared with the preoperative scores ($P < .001$) (Table 2). Patients treated acutely (≤6 weeks) had significantly lower preoperative SF-12 PCS, WOMAC, and Lysholm scores than patients treated in the chronic phase (>6 weeks) ($P < .01$). At final follow-up, there were no differences between patients treated in the acute and chronic phases ($P > .05$) (Table 3). Preoperative WOMAC ($P < .001$) and Lysholm ($P = .005$) scores were significantly different among groups, with the combined ACL + PCL–based group exhibiting worse scores. There was no significant difference among the 3 groups (ACL-, PCL-, and ACL + PCL–based cohorts) for postoperative Tegner, Lysholm, WOMAC, and SF-12 PCS scores ($P > .05$); however, patient satisfaction was significantly different among groups ($P = .041$), favoring ACL-based injuries (Table 4). Overall, there were 9 (4.6%) patients with knee ligament failures after primary reconstruction. Details of all patients with ligamentous failures are reported in the Appendix (available in the online version of this article).

Acute vs Chronic Multiligament Reconstruction

In total, 153 patients were treated in the acute phase (≤6 weeks) and 41 in the chronic phase. Patients treated acutely had significantly lower preoperative SF-12 PCS ($P = .017$), WOMAC ($P < .001$), and Lysholm ($P < .001$) scores when compared with patients treated in the chronic phase. At final follow-up, there was no significant difference in postoperative Tegner ($P = .086$), Lysholm ($P = .268$), WOMAC ($P = .682$), and SF-12 PCS ($P = .077$) scores and patient satisfaction ($P = .414$) between patients treated in the acute and chronic phases (Table 3).

ACL- vs PCL-Based injuries

A total of 141 patients had ACL-based injuries, 26 had PCL-based injuries, and 27 had both ACL and PCL tears.

TABLE 5
Anterior Knee Stability on Physical Examination As Reported by Subjective Grading of Lachman and Pivot-Shift Maneuvers for All ACL-Based Injuries (n = 168) at Minimum 1-Year Follow-up[a]

	Grade, n (%)			
Test	0	1	2	3
Lachman				
Preoperative	0 (0)	1 (0.6)	91 (54.2)	76 (45.2)
Postoperative	141 (84.0)	19 (11.3)	6 (3.6)	2 (1.1)
Pivot Shift				
Preoperative	0 (0)	1 (0.6)	96 (57.1)	71 (42.3)
Postoperative	159 (94.6)	1 (0.6)	7 (4.2)	1 (0.6)

[a]ACL, anterior cruciate ligament.

TABLE 6
Pre- and Postoperative Stress Radiographs for All Patients With MCL, PCL, and FCL/PLC Injuries According to Valgus, Posterior Kneeling, and Varus Stress[a]

Stress Radiograph	Preoperative	Postoperative	*P* Value
Valgus (MCL), n = 98	3.4 ± 0.9	0.2 ± 0.7	.002
Range	2.0 to 8.0	–1.3 to 2.5	
95% CI	3.2 to 3.5	0.1 to 0.3	
Posterior kneeling (PCL), n = 53	12.5 ± 2.9	1.2 ± 1.3	<.0001
Range	8.0 to 21.0	–2.0 to 5.3	
95% CI	11.6 to 13.2	0.8 to 1.5	
Varus (FCL/PLC), n = 114	2.9 ± 0.9	–0.1 ± 0.8	<.0001
Range	2.0 to 8.0	–3.0 to 2.8	
95% CI	2.7 to 3.1	–0.2 to 0.04	

[a]All measurements are reported in millimeters (mean ± SD). FCL, fibular collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament; PLC, posterolateral corner.

Preoperative WOMAC ($P < .001$) and Lysholm ($P = .005$) scores were significantly different among groups, with the combined ACL + PCL–based group exhibiting worse scores. There was no significant difference among the 3 groups for postoperative Tegner ($P = .917$), Lysholm ($P = .400$), WOMAC ($P = .277$), and SF-12 PCS ($P = .236$) scores; however, there was a significant difference among groups with respect to patient satisfaction ($P = .041$), favoring ACL-based injuries (Table 4).

Objective Outcomes

All patients had clinical follow-up with stress radiographs at least 12 months after surgery (mean: 2.0 years, range: 12 months–8 years). The mean knee hyperextension was –3.4° ± 3.7° preoperatively and –1.3° ± 2.0° postoperatively. The mean knee flexion was 133.8° ± 7.2° preoperatively and 134.1° ± 5.0° postoperatively. For ACL-based injuries, frequencies of Lachman and pivot-shift testing grades for pre- and postoperative conditions are reported in Table 5. There were significant improvements in stress radiographs from pre- to postoperative states for all patients with MCL, PCL, and FCL/PLC-based injuries (Table 6). Postoperative stress radiographs of an included patient are presented in Figure 3.

Complications and Failures

There were 28 (14.4%) complications reported in 28 patients. The most common complication was arthrofibrosis (n = 18, 9.3%), in which all patients underwent reintervention surgery to improve knee ROM at a mean 4.9 months after the index procedure. All 18 patients who developed arthrofibrosis underwent surgery in the acute phase (odds ratio, 0; 95% CI, 0-0.79; $P = .015$). Sex ($P = .319$) and MCL reconstruction ($P = .806$) were not significantly associated with arthrofibrosis. Details of each complication are reported in Table 7.

There were 9 (4.6%) patients with knee ligament failures after primary reconstruction. All patients reported reinjuries and subsequent knee instability at a mean 26.2 months after the index surgery. Details of all patients with ligament reconstruction failures are reported in the Appendix (available online).

DISCUSSION

The most important finding of this study was that significantly improved postoperative outcomes with low complication rates were achieved after single-stage reconstruction of all torn knee ligaments in sports-related multiple-ligament knee injuries with immediate postoperative rehabilitation. Moreover, ACL- and PCL-based multiligament reconstructions had comparable results in the context of these multiligament injuries. The findings of the present study indicate that with biomechanically validated, anatomic-based ligament reconstructions, performed in a single stage allowing for immediate ROM, significantly improved postoperative outcomes regardless of the ligament injury pattern were obtained.

The present study further reinforces the findings suggested by previous systematic reviews. In a summary of 11 studies with 320 patients, patients with earlier surgery (<4 weeks) and early knee motion had significantly improved Lysholm scores compared with patients with delayed surgery.[43] In addition, a meta-analysis by Hohmann et al,[14] which included 8 studies and 260 patients, reported that patients with early surgery (<3 weeks) had significantly improved Lysholm scores compared with those with delayed surgery. While these studies were more heterogeneous than the present study in the types of cases analyzed, we found that patients in this sports-related injury cohort with early surgery had significantly improved function. Using stress radiographs, we also objectively validated that the early knee motion program did not result in the reconstruction grafts stretching out.

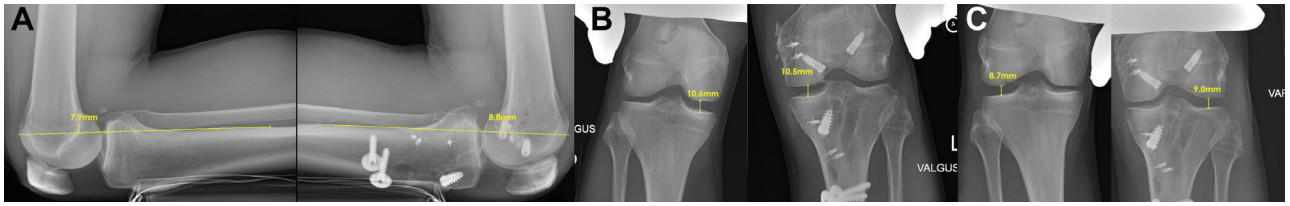

Figure 3. Postoperative radiograph series in the same patient as Figure 1 with a single-stage double-bundle PCL reconstruction, ACL reconstruction, FCL reconstruction, and sMCL reconstruction. Twelve-month postoperative (A) kneeling stress radiographs, (B) valgus stress radiographs, and (C) varus stress radiographs. The patient had full knee motion by 8 weeks postoperatively, and all stress radiographs demonstrated <1 mm of side-to-side difference. ACL, anterior cruciate ligament; FCL, fibular collateral ligament; PCL, posterior cruciate ligament; sMCL, superficial medial collateral ligament.

TABLE 7
Patients With Reported Complications After Multiligament Knee Surgery (n = 28)[a]

	n (%)	Details	Additional Surgery
Arthrofibrosis	18 (9.2)	Knee extension deficits, n = 5; knee flexion deficits, n = 13	Arthroscopy, lysis of adhesions, manipulation under anesthesia
DVT	3 (1.5)	Resolved with designated treatment	NA
Hardware migration	3 (1.5)	Intra-articular migration of proximal MCL anchor	Deep hardware removal
Painful hardware	2 (1.0)	Tibial screw fixation of PCLR	Deep hardware removal
Infection	1 (0.5)	Superficial MRSA infection 3 wk postoperative	Irrigation and debridement
Pneumonia	1 (0.5)	Resolved with designated treatment	NA

[a]Percentages are based on total sample size (N = 194). DVT, deep venous thrombosis; MCL, medial collateral ligament; MRSA, methicillin-resistant *Staphylococcus aureus*; NA, not applicable; PCLR, posterior cruciate ligament reconstruction.

In the present study, there was no significant difference in the postoperative functional and objective outcomes scores between the ACL- and PCL-based multiligament injuries. We believe that this is due to the use of a double-bundle PCL reconstruction technique and modern rehabilitation principles. Historically, outcomes after surgical treatment of PCL tears were believed to be less than optimal, likely secondary to the lack of anatomic and biomechanical restitution, the lower incidence of PCL surgery (and therefore less operative experience for most surgeons), and the more demanding nature of PCL reconstructions.[13] Furthermore, studies have reported that some patients treated with single-bundle PCL reconstructions had persistent instability and developed osteoarthritis at long-term follow-up.[18,42] However, recent biomechanical studies demonstrated that an anatomic double-bundle PCL reconstruction better restores knee kinematics than single-bundle techniques,[17,49] and a recent systematic review supported these biomechanical findings based on clinical findings.[1]

Outcomes for patients with lateral-sided knee injuries also improved significantly in this cohort. Historically, the PLC was regarded as the "dark side" of the knee because of the poor outcomes reported after injuries.[23] A better understanding of the PLC anatomy and biomechanics has led to anatomic-based reconstructions, which yield improved outcomes.[10,26] Geeslin and LaPrade[10] indicated improved outcomes after an anatomic reconstruction of isolated and combined PLC injuries in 29 patients with a mean follow-up of 2.4 years. It was recently reported that repair of collateral ligaments was associated with poorer outcomes and high reoperation rates.[19,33,45] In the present study cohort, all collateral ligaments were treated with biomechanically validated reconstructions.[26,35,50] A recent systematic review on acute PLC injuries documented that reconstruction of PLC tears resulted in better outcomes than did repairs.[11,39] In addition, King et al[19] noted that patients who underwent repair of the MCL in multiligament injuries were less likely to achieve good results. The present study validates that an immediate postoperative ROM program with anatomic-based ligament reconstructions was safe and resulted in low rates of arthrofibrosis (<10%). Furthermore, there was no significant difference in the rate of arthrofibrosis between medial- and lateral-based multiligament injuries.

All ligament reconstructions in this patient cohort were performed with a single-stage surgical procedure, followed by knee ROM and rehabilitation initiated on postoperative day 1. Some authors have advocated for a staged ligament reconstruction because of the extended same-day surgery time associated with multiligament reconstructions and an increased risk of arthrofibrosis owing to a delay in the rehabilitation process.[9,16,38] In a systematic review of 24 studies, Mook et al[38] reported no significant difference in the number of patients requiring manipulation under anesthesia or operative arthrolysis when comparing acute treatment and staged treatment of multiligament knee injuries. Failure to reconstruct some ligaments during

a single-stage procedure can result in altered knee kinematics, leading to nonphysiologic loading of the knee and reconstruction grafts[28,29] and potentially to graft failure. Furthermore, joint reduction can be more challenging in a staged procedure, which can lead to abnormal force transmission through the joint[28,29] and early degenerative changes. Early mobility was not associated with recurrent joint instability but rather with less joint instability in all directions in patients who were allowed early postoperative mobility in the acute treatment group. Mook et al also noted that early rehabilitation was associated with a greater percentage of patients returning to work.

Some limitations are acknowledged for this study. First, nearly 30% of the eligible cohort was lost to follow-up. However, this subset did not significantly differ on baseline demographics (except sex), injury pattern, or baseline patient-reported outcome scales. Thus, it was not expected that these results were biased owing to the lost follow-up group. The injury patterns were diverse, which reflects the nature and complexity of these low-velocity sports-related injuries. The fact that an experienced surgeon in a tertiary referral center performed all surgical procedures might not make these results generalizable. However, this was a large series of patients from a single surgeon's experience, which eliminated several variables, such as differing surgical techniques and rehabilitation protocols from multicenter studies. Furthermore, the utilization of biomechanically and clinically validated reconstruction techniques enhances the external validity of this study.

The findings of this study support the early and single-stage anatomic-based surgical treatment of multiple-ligament sports-related knee injuries. In particular, early knee motion had a low risk of arthrofibrosis, and the early postoperative knee motion program did not result in the surgical reconstructions stretching out. In addition, multiple-ligament knee injuries with double-bundle PCL reconstructions had similar outcomes to those with ACL reconstructions. We recommend that this treatment protocol be utilized in patients with multiple-ligament sports injuries.

CONCLUSION

These results demonstrated that single-stage anatomic-based knee ligament reconstructions with immediate postoperative rehabilitation in the setting of sports-related multiligament injuries yielded comparable and significantly improved outcomes irrespective of the ligament injury pattern. In addition, there was no difference in outcomes between ACL- and PCL-based injuries in the setting of sports-related multiligament injuries.

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