Repair of Acute Grade 3 Combined Posterolateral Corner Avulsion Injuries Using an Enhanced Fixation Technique

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Background: Previous studies have suggested that surgical repair of the posterolateral corner (PLC) may be inferior to reconstruction.

Hypothesis: We hypothesized that acute repair (<3 weeks) of avulsion-type PLC multiligament knee injuries with no midsubstance injury would lead to lower failure rates than previously reported for PLC repair.

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

Methods: A total of 28 patients with multiligament knee injuries who underwent acute repair between January 2007 and June 2018 of a PLC avulsion injury with no evidence of midsubstance tearing were included. All PLC avulsion injuries were treated using a transosseous Krackow suture pull-through technique without graft augmentation. Outcome metrics included lateral joint-space widening with varus stress, patient-reported clinical varus instability, patient-reported outcome measures (PROMs), and any subsequent revision or salvage procedure.

Results: The mean time from injury to repair was 8.1 ± 5 days. At a mean follow-up of 2 years (range, 3-90 months), clinical varus stress examination at 30° demonstrated a significant reduction in lateral compartment opening, from 9 ± 3 mm preoperatively to 0 ± 3 mm ($P < .0001$). The failure rate was calculated to be 10.7% (3/28), which was significantly lower than the failure rate from a 2016 systematic review (38%, 17/45; $P = .015$). Of the 28 patients, 21 (75%) had PROM scores. Patients who underwent staged bi-cruciate reconstructions (n = 5) had significantly higher subjective International Knee Documentation Committee (IKDC) (87.2 vs 65.5; $P = .014$) and Lysholm (90.5 vs 75.2; $P = .029$) scores compared to patients with untreated bi-cruciate injuries (n = 9). Patients with peroneal nerve injury (n = 4) had significantly lower IKDC (58.2 vs 80.8; $P = .0045$) and Tegner (3.2 vs 5.4; $P = .047$) scores than those without peroneal nerve injury (n = 17). The mean IKDC and Lysholm scores at final follow-up were 73.4 ± 24.0 and 80.8 ± 23.1 at 7.1 years (range, 2.3-10.6 years) of follow-up.

Conclusion: Repair of acute grade 3 combined PLC avulsion injuries using a transosseous Krackow suture pull-through technique demonstrated a failure rate of 10.7%. Patients who underwent a staged cruciate reconstruction(s) had higher subjective outcome scores than those who had cruciate injuries left untreated. Peroneal nerve injury was associated with lower outcome scores.

Keywords: posterolateral corner injury; posterolateral corner repair; enhanced technique; multiligament knee injury; knee dislocation; peroneal nerve injury; reconstruction

The posterolateral corner (PLC) of the knee consists of both static and dynamic stabilizers.[3,5,9,14,21] For grade 3 isolated and combined PLC injuries, worse outcomes have been reported with nonoperative treatment, and the general consensus is often in favor of operative treatment for these injuries.[9,11-14,21] While recently there has been an increased focus directed at better understanding the PLC injuries and their subsequent treatment, there is no consensus for the best treatment of acute combined PLC injuries, which can include either direct repair, repair with augmentation, or reconstruction.[9,11-14,21]

Studies have implicated that PLC repair confers inferior outcomes compared to reconstructions in the acute setting, with older studies reporting upwards of 40% of repairs needing a subsequent revision procedure or reconstruction.[15,16,21] Acute PLC reconstructions, on the other hand, have reported failure rates in the range of 8% to 9%.[6,15,21] As a result, some have advocated for only performing PLC

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reconstruction rather than repair, even in acute injuries.[15,21] Currently, this perspective is grounded on only low-level evidence from studies with limited power, follow-up, and/or variable repair techniques.[10,15,21]

Recently, there has been a renewed interest regarding acute repair of grade 3 PLC injuries. LaPrade et al[8,9,11,14] demonstrated improved outcomes after PLC repair in select patients with 2-year follow-up data. The authors showed acute PLC repair was best in the setting of avulsions with adequate tissue quality, and reserved reconstructions or augmentations for patients with midsubstance tears, chronic instability, and those with poor tissue quality. More recently, there has been an impetus for understanding how proper patient selection may influence repair outcomes.[1,20] However, while our understanding of the repair technique has improved over the years, there remains a lack of consensus on whether repair or reconstruction should be performed for acute combined PLC injuries.[2,21,22]

The primary aim of this study was to report long-term clinical and functional outcomes in patients who underwent acute repair of grade 3 combined PLC avulsion-type injuries with a standardized technique. We hypothesized that acute repair (<3 weeks) of avulsion-type PLC multiligament knee injuries (MLKIs) with no midsubstance injury would lead to lower failure rates than those previously reported in the literature for PLC repair.

METHODS

At a level 1 trauma center, the case log of a single surgeon (M.J.M.) was reviewed for patients who had MLKIs between the years of 2007 to 2018. Patients were retrospectively identified within the electronic medical record using Current Procedural Terminology (CPT) and International Classification of Disease (ICD) procedural codes. Coding for ICD included those that pertained to the management of lateral (fibular) collateral ligament (LCL) injury, and the following CPT code was utilized: 27427.

A total of 68 patients with MLKI treated surgically for a combined PLC injury were identified. All injuries were classified via the Schenck classification, and by definition, all patients had combined PLC and cruciate injuries. A grade 3 PLC injury was defined as a complete disruption of the LCL (complete midsubstance tear or avulsion) and a complete tear or avulsion of at least one of the following: biceps femoris tendon, popliteofibular ligament, or popliteus tendon.[7] Inclusion criteria from this data set included any acute MLKI treated with surgical repair without graft augmentation of an avulsion-type grade 3 PLC injury without midsubstance tearing within 3 weeks of injury. This was done by reviewing the operative records for each patient, with a review of the magnetic resonance imaging (MRI) scan to confirm presence of a grade 3 PLC avulsion injury. All injuries were initially identified by a board-certified musculoskeletal radiologist on MRI, which was then reviewed by a board-certified orthopaedic sports medicine surgeon (M.J.M.). Ligament injuries of the PLC were categorized according to the classification described by Kahan et al.[7] For a given MRI scan, if a discrepancy existed, or documentation was unclear, the operative description of the injury was used for the definitive diagnosis. This identified 28 patients who sustained a MLKI with a grade 3 PLC avulsion injury. Exclusion criteria included additional, unrelated simultaneous knee surgery (n = 0), prior ipsilateral knee surgery (n = 0), follow-up of <2 years (n = 4), or missing patient-reported outcome data (n = 3).

The indications for performing the same uniform acute PLC repair technique in this study included the following: (1) <3 weeks from initial injury; (2) only avulsion-type injury; and (3) no evidence of midsubstance injury on MRI nor on intraoperative assessment. In contrast, patients with MRI and/or intraoperative evidence of midsubstance tearing, and those with chronic injuries, were considered potentially irreparable and were treated with a PLC reconstruction. Patients with evidence of both avulsion and midsubstance injuries were treated with combined repair and graft augmentation and were excluded from the study cohort. The extent and location of injury was recorded intraoperatively, and procedural technicalities were well-documented by the senior author, a board-certified orthopaedic sports medicine surgeon with over 20 years of experience (M.J.M.). Repair failure was defined as any of the following: (1) subsequent or revision or salvage surgery on the ipsilateral knee; (2) comparative lateral joint-space widening ≥4 mm with subjective clinical varus stress; or (3) documentation noting both subjective and objective varus instability.

Findings from the preoperative physical examination and subsequent follow-up were collected, including varus instability at 30° of flexion with manual estimated lateral compartment opening measurements (0, 3, 6, 9, 12, or 15 mm). When present, peroneal nerve injuries were defined as a deficit in at least one of the following measures:

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Ethical approval for this study was obtained from Yale University (reference No. 2000028578).

tibialis anterior or extensor hallucis longus strength or peroneal nerve distribution sensory deficits.

Cross-Sectional Data Collection

Cross-sectional data were collected over the telephone during the time this study was conducted, which included patient-reported outcome measures (PROMs) and any subsequent ipsilateral knee surgery. The PROMs used were the International Knee Documentation Committee subjective knee form (IKDC), the Lysholm score, the Tegner activity scale, and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).

Surgical Technique

Incisions were typically started along the lateral epicondyle and extended to the level of the proximal fibular shaft, which varied based on the zone of injury (proximally vs distally based injury). This incision results in exposure of the entire fibular head and neck and the common peroneal nerve at the fibular neck and was extended for additional anterior exposure when treating iliotibial band avulsion injuries.

For distally based PLC injuries, a peroneal neurolysis was part of the surgeon's approach and was used to identify, inspect, and protect the peroneal nerve during the procedure.[5] A tag suture was placed into the soft tissue avulsion, which allowed distal traction to better delineate the structures. The popliteofibular ligament (PFL) was routinely assessed by retracting the common biceps femoris tendon proximally and visualizing the fibular styloid. In most cases, the PFL was also avulsed and retracted along with the other structures, as a combined sleeve of tissue. The individual structures were not dissected out but the avulsed connective tissue sleeve was maintained in situ.

Locking Krackow (No. 2 abrasion-resistant) sutures were then placed into each injured structure (either the LCL and biceps femoris tendon and/or PFL), typically with 2 sets of sutures in each, without dissecting them out and separating the individual structures. We feel there are several enhancements to previously described techniques, as typically multiple sets of locked sutures can be placed into the avulsed structures. This allows for uncompromised tension being able to be placed on the avulsed structures, which is then able to be serially tensioned on the dense anteromedial cortex of the proximal tibia, as described later. Occasionally, cortical bone fragments are contained within the avulsed soft tissue sleeve and are typically included in the repair to potentially improve healing secondary to bone-to-bone incorporation. When the avulsion is off the fibula, the repair technique utilizes fibular-tibial transosseous tunnels created by drilling 2 Beath pins through the fibular head, across the tibia, and exiting through the anteromedial tibial cortex. We aim to place these exiting the anteromedial tibia approximately 4 cm distal to the tibial tubercle to avoid the region of simultaneous or future cruciate ligament reconstruction tibial tunnel entrance. These pins were started at both the anterior and posterior margins of the fibular head, approximately 1 cm distal to the proximal aspect of the fibular head. The LCL sutures are passed through the anterior tunnel and the biceps/PFL are passed through the posterior tunnel. If there is a posterolateral capsular injury, which most commonly occurs at the midsubstance region and less commonly as an avulsion off the tibia, a side-to-side repair (midsubstance) or suture anchor fixation to the tibia (avulsion) is routinely performed. Preparation of a distal avulsion repair is demonstrated in Figure 1.

A small incision over the anteromedial tibial cortex was used to retrieve the sutures, and both suture sets were tied over the same metal button. A non-self-tensioning button has been utilized in this technique. For tensioning the LCL sutures, the knee was placed in 30° of flexion with a slight valgus force when tied, while the biceps and/or PFL sutures were tensioned and tied with the knee near extension (Figures 2 and 3).

Avulsion fractures of the fibular head (arcuate fractures) were treated in a similar manner to pure soft tissue avulsions. However, this was frequently augmented with cerclage using a high-strength suture through the fibular neck in the sagittal plane or, less commonly, a sternal wire, for additional compression. Preoperative and postoperative MRI examples of a distal PLC and fibular styloid avulsion injury and post repair are shown in Figure 4.

For proximally based PLC injuries, the distal soft tissue and peroneal nerve were left in situ. The iliotibial band was incised at the level of the lateral epicondyle and the proximal attachment sites of the LCL and popliteus tendons were localized on the posterolateral femur. Occasionally, the joint capsule was intact, and even after exposure of the LCL, the popliteus tendon was not regularly visualized. In these scenarios, a vertical incision was made through the lateral capsule over the popliteal sulcus, which exposed the femoral attachment site of the popliteus tendon. If avulsed, the tendon was traced to the posterolateral aspect of the joint behind the lateral meniscus. If the remaining tendon was intact with no evidence of midsubstance injury, locking sutures were placed within the tendinous portion in preparation for repair. To assess the integrity of the PFL, a proximally directed tension was applied to the sutured popliteus tendon and the region of the fibular styloid was palpated for discontinuity. The region of the tibial portion of the lateral capsule, since called the anterolateral ligament, was also inspected, and if avulsed off the tibia, suture anchor repair was performed at the tibial attachment site.

Fixation of the proximally based popliteus tendon and LCL injuries was done via a transosseous pull-through technique with similar methodology for distally treated injuries. It is important to note that the starting points for the pins are placed at the native attachment sites of the aforementioned structures on the lateral condyle and the pins are directed anteriorly to minimize convergence with a planned anterior cruciate ligament (ACL) femoral tunnel. Next, the Krackow sutures in the proximal segments are pulled through the native femoral attachment sites using Beath pins, and both sutures are tied over the same metallic button, to minimize suture erosion through the bone on the medial femoral cortex.

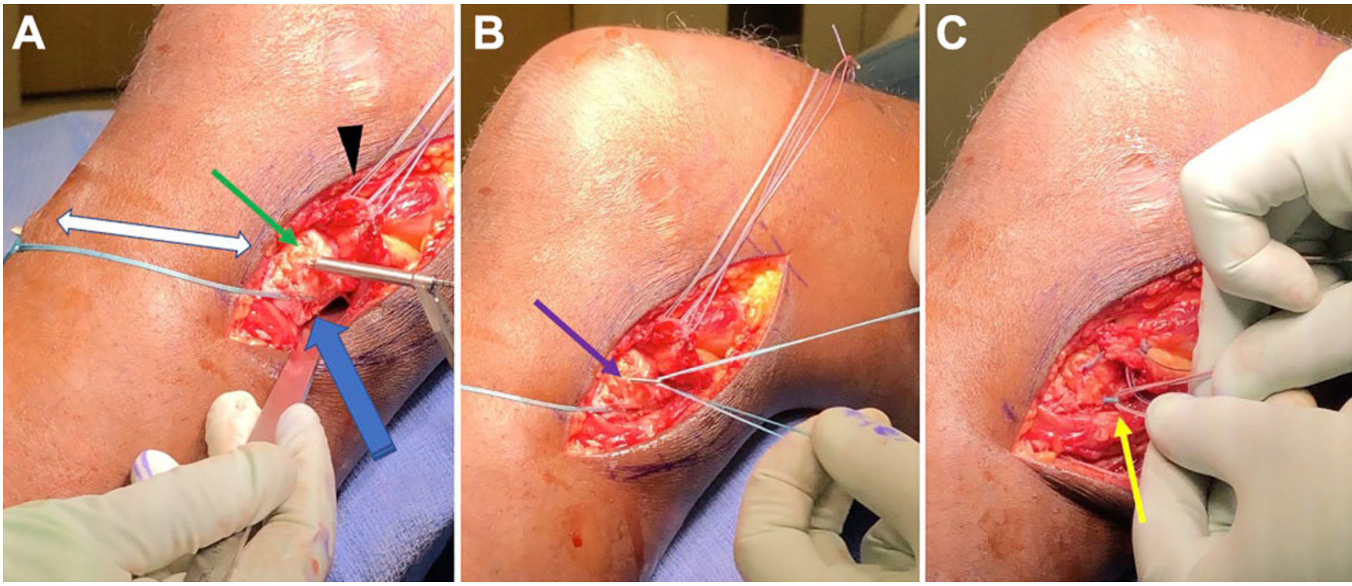

Figure 1. (A) Beath pin (thin green arrow) being drilled through the anterior aspect of the fibular head across to the anteromedial tibia. The white double arrow indicates the path of the drill through the proximal fibula to the anteromedial tibia; the thick blue arrow shows the retractor around the fibular head protecting the peroneal nerve, seen wrapping around the fibular neck; the black arrowhead indicates Krackow sutures placed in the avulsed soft tissue sleeve of the biceps-LCL-PFL. (B) Beath pin pulling through passing sutures through the anterior tunnel of the fibular head (purple arrow). (C) Passing sutures pulling the posterior limb of the Krackow sutures through the posterior tunnel of the fibular head (yellow arrow). LCL, lateral collateral ligament; PFL, popliteofibular ligament.

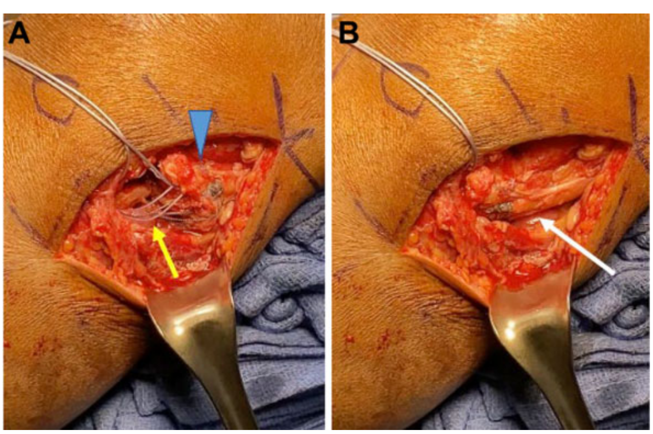

Figure 2. (A) The combined sleeve of LCL-biceps femoris-PFL (blue arrowhead) with locking Krackow sutures in place (yellow arrow) which are passed through the fibular head. (B) The biceps femoris tendon (white arrow) repositioned onto the fibular head. LCL, lateral collateral ligament; PFL, popliteofibular ligament.

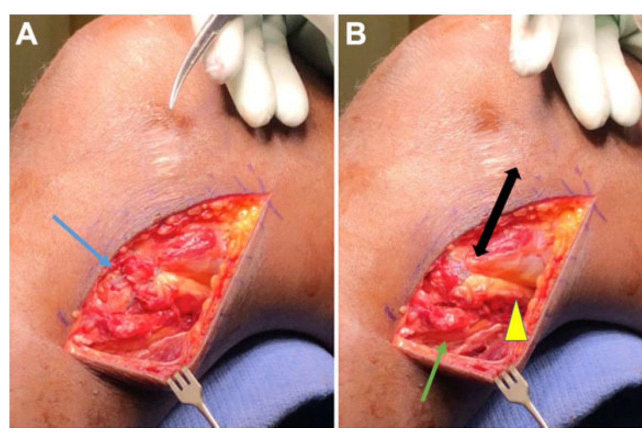

Figure 3. (A) Krackow sutures (blue arrow) are placed through the anterior tunnel of the fibular head. The sutures are not yet tensioned or tied. (B) Krackow sutures that have been tensioned and tied over the anteromedial tibial cortex. Double black arrow indicates the course of the LCL, the thin green arrow indicates the peroneal nerve, and the yellow arrowhead indicates the biceps femoris tendon. LCL, lateral collateral ligament.

Statistical Analysis

An a priori power analysis was conducted to determine the necessary sample size for the primary outcome of failure rate. Based on a systematic review on PLC injuries that was published in 2016,[6] PLC repair exhibited a reported failure rate of 38% (17/45), with the largest single PLC repair cohort[21] reported to date exhibiting a 37% (13/35) failure rate. The failure rate in that review was preemptively estimated to be approximate to the reported rate of failure for acute reconstruction, hybrid repair, or local tissue advancements (9%).[6] To detect a difference with an

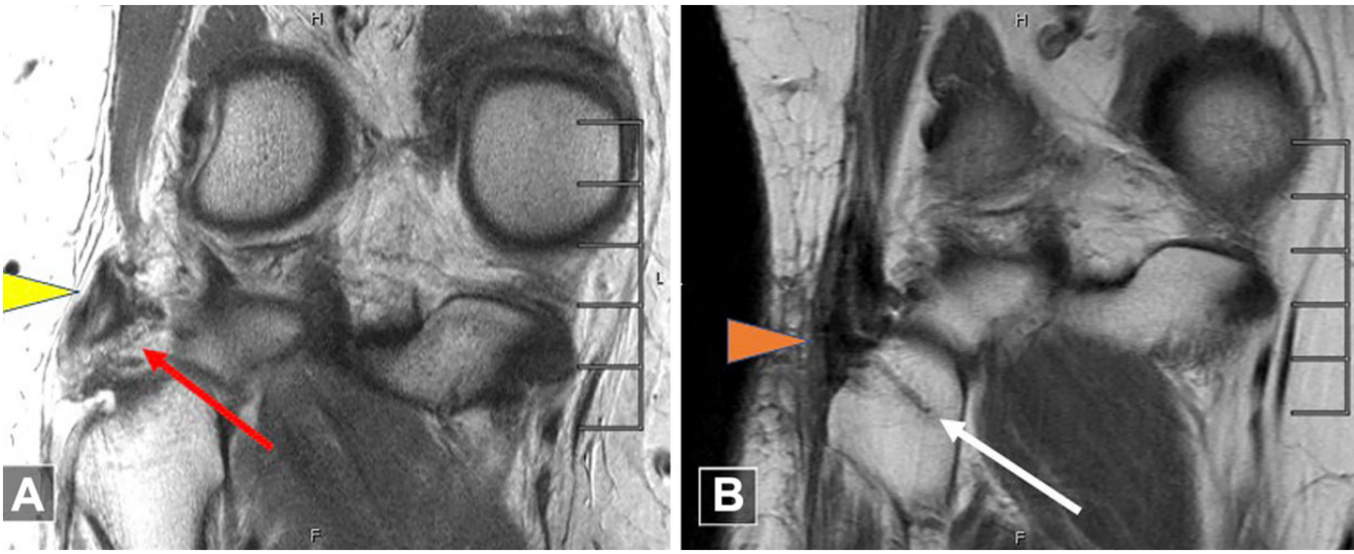

Figure 4. (A) MRI showing PLC avulsion injury with biceps femoris tendon (yellow arrowhead) attached to the avulsed fibular styloid fracture fragment (red arrow). (B) MRI at 3 months after repair demonstrating the healed biceps femoris tendon and fibular styloid (orange arrowhead). The white arrow represents the drill hole path through the fibular head and heading toward the anteromedial tibia. MRI, magnetic resonance imaging; PLC, posterolateral corner.

TABLE 1
Patient Demographics (N = 28)[a]

Characteristic	Value
Age, y	31.8 ± 12.1
Male sex	19 (67.8)
BMI	32.5 ± 11.3
Mechanism of injury	
High velocity	21 (75)
Fall	3 (11)
Sports	3 (11)
Ultra-low velocity	1 (3)

[a]Data are presented as n (%) or patients or mean ± SD. BMI, body mass index.

TABLE 2
Associated Injuries (N = 28 patients)[a]

Injury	No. of Patients
Dislocation	6 (21)
Fracture	4 (14)
Peroneal nerve injury	8 (29)
Vascular injury	0 (0)
Ligamentous injury patterns	
ACL-PCL-PLC	18 (64)
ACL-PLC	7 (25)
PCL-PLC	3 (11)
Biceps femoris tendon avulsion	14 (50)
ITB avulsion	32% (N=9)

[a]Data are presented as n (%). ACL, anterior cruciate ligament; ITB, iliotibial band; PCL, posterior cruciate ligament; PLC, posterolateral corner.

incidence of 9% failure in the study group compared to 38% in a population, alpha was set to .05 and beta to .20, indicating 17 patients would be necessary for this portion of the study.

Subsequent statistical analyses were performed using chi-square and Fisher exact tests for categorical variables and Student *t* tests for continuously distributed variables. All statistical analyses were performed using Stata 13.1 (StataCorp) or Microsoft Excel (Microsoft). Statistical significance was set as $P < .05$ and 2-sided.

RESULTS

Patient Demographics and MLKI Patterns

In total, 28 patients who underwent PLC repair surgery were identified. The mean time between initial injury and PLC repair was 8.1 ± 5 days. Data pertaining to patient demographics and mechanism of injury are listed in Table 1. The most common type of injury was ACL-posterior cruciate ligament (PCL)-PLC (64%, N=18), followed by ACL-PLC (25%, N=7), and PCL-PLC (11%, N=3) (Table 2).

Of the 28 patients, 6 (21%) had a documented knee dislocation at presentation. Additionally, 4 (14%) of the 28 patients had an associated fracture, which included 3 anteromedial rim fractures of the medial tibial plateau and 1 posterolateral tibial plateau fracture. Eight patients (29%) had an associated peroneal nerve injury, and none had an associated vascular injury that required surgical intervention (Table 2).

All 28 (100%) patients with MLKI had complete PLC avulsions, with 23 (82%) distally based (fibular) avulsions and 5 (18%) proximally based avulsions (Figures 5 and 6).

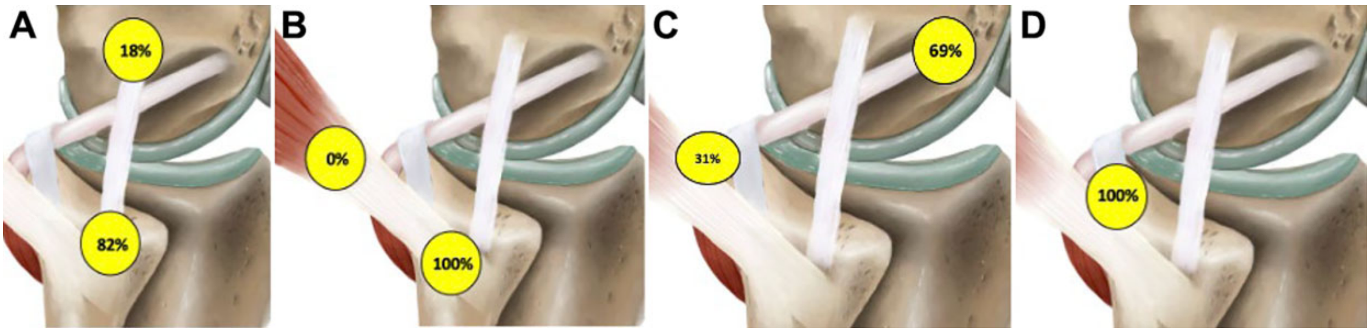

Figure 5. (A) The location of injury to the LCL was observed in the following frequencies: 18% (n = 5) of injuries were femoral-sided injuries, 0% were a midsubstance tear, and 82% (n = 23) were an avulsion off of the fibular head. (B) The location of injury to the biceps femoris was observed in the following frequencies: 100% (n = 14) of injuries were an avulsion off of the fibular head and 0% were an injury at the myotendinous junction. (C) The location of injury to the popliteus tendon was observed in the following frequencies: 69% (n = 9) were femoral-sided injuries, 0% were midsubstance, and 31% (n = 4) were at the myotendinous junction. (D) The location of injury to the popliteofibular ligament was observed in the following frequencies: 100% (n = 12) of injuries were an avulsion off of the fibular head. Image adapted from Kahan JB, Li D, Schneble CA, et al. The pathoanatomy of posterolateral corner ligamentous disruption in multiligament knee injuries is predictive of peroneal nerve injury. *Am J Sports Med*. 2020;48(14):3541-3548. LCL, lateral collateral ligament.

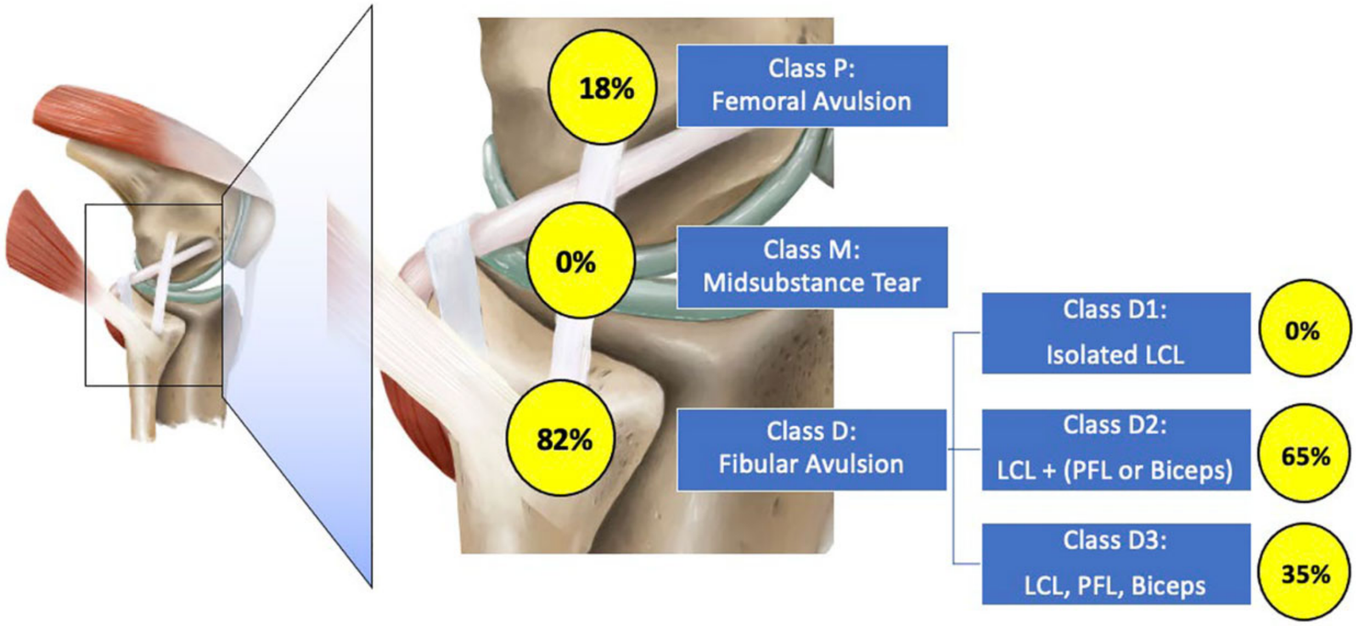

Figure 6. Posterolateral corner injury classification system according to Kahan et al.[7] The injuries were classified into 3 main classes based on location to the LCL: class P (proximal) femoral avulsion (n = 5, 18%), class M midsubstance tear (n = 0), and class D (distal) fibular avulsion (n = 23, 82%). Class D injuries were subclassified based on the number of structures avulsed from the fibular head: class D1 (n = 0), class D2 (n = 15, 65%), and class D3 (n = 8, 35%). Image adapted from Kahan JB, Li D, Schneble CA, et al. The pathoanatomy of posterolateral corner ligamentous disruption in multiligament knee injuries is predictive of peroneal nerve injury. *Am J Sports Med*. 2020;48(14):3541-3548.

Operative Management of Cruciate and/ or Bi-cruciate Injuries

Of the 28 patients, 18 (64%) underwent isolated PLC repair with no subsequent uni-cruciate or bi-cruciate staged procedure. Of these 18 patients, 11 (61%) had bi-cruciate (ACL-PCL) tears, 5 (28%) had uni-cruciate ACL tears, and 2 (11%) had uni-cruciate PCL tears. For these patients who had uni-cruciate (n = 7) or bi-cruciate ruptures (n = 11) without staged reconstructions, the reasons for not proceeding with staged reconstruction included no symptoms or complaints of knee instability (n = 12), social reasons or lost to follow-up (n = 4), and knee stiffness or medical reasons (n = 4). For the remaining 10 patients in the cohort, 7 underwent staged bi-cruciate reconstruction(s), 2 underwent staged ACL reconstructions, and 1 patient was treated with a concurrent PCL avulsion repair during the acute PLC repair.

Postoperative Clinical Assessment and Failure Rate

Pre- and postoperative clinical varus stress testing at 30° was available for 24 of the 28 patients. Clinical lateral compartment opening with varus stress decreased significantly ($P < .0001$) from 9 ± 3 mm preoperatively to 0 ± 3 mm (range, 0-6 mm) at the time of most distant in-person follow-up (mean follow-up, 2 years; range, 3-90 months). The failure rate was calculated to be 10.7% (3/28) and was significantly smaller than the reported failure rate of 38% (17/45) as reported in a systematic review[6] ($P = .015$). Of note, 2 patients went on to develop clinical varus instability with lateral joint line widening >4 mm within 14 months after the procedure, and a third patient went on to a total knee arthroplasty at 2-year follow-up. All 3 patients had a cruciate or bi-cruciate injury (in addition to a PLC repair) that was left untreated and did not undergo a cruciate reconstruction.

TABLE 3
Patient-Reported Outcome Measures (N = 21 patients)[a]

Outcome Measure	Score
IKDC	73.4 ± 24.0
Lysholm	80.8 ± 23.1
Tegner	
Preinjury	6.7 ± 1.8
Postinjury	4.9 ± 2.2
Change	–1.8 ± 1.7
WOMAC	20.8 ± 17.8
IKDC >75	55%
Lysholm >75	68%

[a]Data are presented as mean ± SD or % of patients. IKDC, International Knee Documentation Committee; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

TABLE 4
PROM Scores Stratified by Ligamentous Injuries (N = 21 patients)[a]

	ACL-PCL-PLC	ACL-PLC	PCL-PLC	P
IKDC	68.8	76.1	92.7	.226
Lysholm	78.1	83.8	90	.782
Tegner	4.5	6	5.7	.66
WOMAC	23.4	19.8	9.3	.017[b]

[a]ACL, anterior cruciate ligament; IKDC, International Knee Documentation Committee; PCL, posterior cruciate ligament; PLC, posterolateral corner; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
[b]Significant difference between the PCL-PLC group compared with the ACL-PCL-PLC and ACL-PLC groups ($P < .05$).

PROM Scores

Of the 28 patients who met the initial inclusion criteria for this study, 21 (75%) patients with >2 years of follow-up were able to be reached for PROMs, information regarding any subsequent ipsilateral surgery, and any experience of subjective varus instability. The 7 patients who could not be reached were excluded from the PROM analysis (Appendix Table A1).

At a mean follow-up of 7.1 years (range, 2.3-10.6 years), the mean subjective IKDC and Lysholm scores for the 21 patients were 73.4 ± 24.0 and 80.8 ± 23.1, and none (0%) underwent additional or revision surgery on the treated knee (Table 3). There was no association between IKDC, Lysholm, and Tegner scores when stratified by ligamentous injury. WOMAC scores were significantly lower in patients with PCL-PLC injuries compared to those with ACL-PCL-PLC and ACL-PLC injuries ($P = .017$) (Table 4).

There was no association between IKDC, Lysholm, Tegner, and WOMAC scores and the presence of documented dislocation, fracture, or number of ligaments injured (Tables 5). However, patients with peroneal nerve injury (n = 4) had significantly lower IKDC (58.2 vs 80.8; $P = .0045$) and Tegner scores (3.2 vs 5.4; $P = .047$) than those without peroneal nerve injury (n = 17) (Table 5). Patients who underwent staged bi-cruciate reconstructions (N = 5) had significantly higher IKDC (87.2 vs 65.5; $P = 0.014$) and Lysholm (90.5 vs 75.2; $P = .029$) scores compared to patients with bi-cruciate injuries left untreated (N = 9) (Table 6).

TABLE 5
PROM Scores Stratified by Associated Injuries (N = 21 patients)[a]

	Dislocation			Fracture			Peroneal nerve injury			Bi-cruciate injury		
	Yes	No	P	Yes	No	P	Yes	No	P	Yes	No	P
IKDC	80.3	71.3	.4730	87	71.2	.3017	48.2	80.8	.0045[b]	68.8	83.2	.1938
Lysholm	80.4	80.9	.9684	79.3	81	.9108	66.2	85.1	.1100	78.1	86.4	.4460
Tegner	5	4.8	.9201	4	5.05	.4595	3.2	5.4	.0477[b]	4.5	5.9	.1778
WOMAC	18.6	21.5	.7593	9.3	22.6	.2373	33	17.2	.0806	23.4	15.3	.3305

[a]IKDC, International Knee Documentation Committee; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
[b]Significant difference in scores between patients with versus without associated injury ($P < .05$).

TABLE 6
PROM Scores Stratified by Bi-cruciate Injury[a]

	PLC Repair With Staged Bi-cruciate Reconstruction (n = 5)	Isolated PLC repair (n = 9)	*P*
IKDC	87.2	65.5	.014[b]
Lysholm	90.5	75.2	.029[b]
Tegner	5.8	4.4	.688
WOMAC	10	27	<.001[b]

[a]IKDC, International Knee Documentation Committee; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

[b]Significant difference in scores between patients who underwent staged versus isolated repair ($P < .05$).

Complications

Three patients had lysis of adhesions with manipulation under anesthesia during the postoperative period. No patients had episodes of deep vein thrombosis or pulmonary embolism during the postoperative hospital stay. Lastly, no patients experienced intraoperative iatrogenic neurovascular injuries, postoperative infections, or required removal of hardware.

DISCUSSION

This study demonstrates that timely acute repair of grade 3 combined PLC avulsion-type injuries in select patients can result in significantly lower failure rates (10.7%) than reported for PLC injuries in general, regardless of how the cruciate injury is addressed. Furthermore, patients who underwent PLC repair with a staged bi-cruciate reconstruction had significantly higher subjective PROMs than patients with PLC repairs who had untreated bi-cruciate injuries. In addition, the presence of a peroneal nerve injury was associated with significantly worse PROMs compared to those without a nerve injury. In this series, there was an acceptable failure rate for acute repair of grade 3 combined PLC injuries at an average of 7 years of follow-up (range, 9 months to 10.6 years), suggesting that acute repair may result in a satisfactory outcome in carefully selected patients.

The current literature available is suggestive of reconstruction providing lower failure rates in comparison to repair for acute grade 3 PLC injuries. In one of the largest studies, Stannard et al[21] reported a 37% (13 of 35) repair failure rate compared to 9% (2 of 22) for the reconstruction failure rate. Similarly, Levy et al[15] described a 40% (4 of 10) repair failure rate compared to a 6% reconstruction failure rate in their cohort. Both of these study populations consisted of a majority of patients who underwent a staged cruciate or bi-cruciate reconstruction after their PLC repair as treatment for their MLKI. These reports of repair outcomes, in contrast to our study, were not restricted to a collection of patients who underwent a relatively uniform procedure for a similar pattern of injury and lacked a detailed description of the repair technique. Despite their utility, these studies still have limitations in power, follow-up, and/or repair techniques.[10,15,21] Our study demonstrated a significantly lower rate of failure (10.7%) in patients with acute repair of combined PLC avulsion type injuries than the repair failure rates of 37% to 40% that have been suggested.[6,15,21] It is important to note that all of the 3 patients who met the definition of failure (>4 mm lateral joint laxity on clinical exam and/or underwent subsequent revisional surgery) had a cruciate injury(s) that was not reconstructed, which could have contributed to the persistent laxity on physical exam that defined 2 out the 3 failures. While the ACL and PCL are secondary stabilizers to varus stress and external rotation and untreated injuries can stress the repaired PLC, it is important to note that 2 of the patients had complete peroneal nerve palsies with a foot drop, and the third had severe knee osteoarthritis before her injury that precluded bi-cruciate reconstruction. Each patient had several risk factors to impart undue stress on their repair, and it is also important to consider whether a combined PLC and cruciate reconstruction would have fared better in these clinical scenarios. Likely, it is a confluence of a few factors that contributed to the failures reported in this study.

The assessment and repair technique were conducted on a relatively uniform group of patients with similar avulsion-type injuries (without any evidence of midsubstance injury). Heterogeneous techniques for PLC repair in isolated and combined cases are reported throughout the literature, making these difficult to interpret findings outside of the technique used.[5,6,17,19,21] These techniques include “en masse surgical repairs” of the avulsed posterolateral structures with staple fixation to the tibia,[19] direct repair of LCL and popliteus tendon avulsions with suture anchors,[15] direct repair of biceps femoris tendon avulsions with fibular head bone tunnels,[4,5] and internal screw fixation of fibular head avulsions.[21] In the present study, the same uniform technique was applied for every repair performed. This consisted of multiple locking Krackow sutures placed in the biceps and LCL, which were passed through remaining intact fibula and tibia, then fixed on the anteromedial tibial cortex. This repair technique has been conducted by the senior author for over 20 years and the reported findings from this study serve as outcome data for this technique.

It is also important to denote the potential mode of failure for this technique. While the reported failure rate (10.7%) and persistent clinical laxity in the 2 patients who did not undergo cruciate reconstruction may provide important information, it is difficult to determine the technical mode of repair failure, as these patients had untreated cruciate injuries and did not undergo a subsequent revision PLC procedure. Stannard et al[21] reported that most repairs in their series failed from subsequent tendinous or midsubstance ligamentous tearing, which was attributed to inadequate soft tissue quality of the repaired structure. Contrary to the findings of Stannard et al, Levy et al reported no correlation between the site of injury and failure; however, this was based on an assessment of only 4 failures, some of which involved anchor failure.[15] The technique described in the current study potentially offers several potential biomechanical advantages against several modes of failure. First, there is added suture security acquired placing the fixation over the dense anterior tibial cortical bone, in comparison to fibular fixation alone. This potentially confers a decreased likelihood of suture or anchor pull-out through bone, which is especially important when dealing with PLC injuries with fragile fibular bone or in situations involving fibular head fractures or arcuate fractures.[5,6] Second, the use of multiple Krackow sutures may potentially have also conferred some degree of protection against suture pull-out from the soft tissue; however, this cannot be concluded from the results of our study. Future studies would be needed to validate the possible biomechanical benefits of this fixation technique. Another potential explanation for the lower failure rate could be the meticulous evaluation of soft tissue quality of the non-avulsed portion of each structure to identify any midsubstance tearing, before proceeding with a repair.

Results with regard to PROMs were modest, with a mean IKDC score of 73.4 ± 24.0 and 55% of patients reaching an IKDC score of ≥75. While these scores seem to fall within a similar range as those reported for PLC reconstruction within the literature,[5] our patients who sustained a peroneal nerve injury from the initial trauma had worse IKDC and Tegner scores compared to those without peroneal nerve injury. This discrepancy is likely the result of the disability associated with the peroneal nerve injury rather than a reflection of the PLC repair. Prior studies have demonstrated poor functional recovery in patients with a complete peroneal nerve palsy in the setting of an MLKI.[1,7,18] In our study, 1 patient developed a complete peroneal nerve palsy with no recovery at the 3-year follow-up. This patient used an ankle foot orthosis and declined any additional surgical intervention such as tendon transfers to address the foot drop. There were 3 patients with partial peroneal nerve palsies, all reporting a subjective degree of improvement or full improvement in function and/or sensation at the 2-year follow-up. Currently, there are limited outcome data on patients treated for acute PLC repair with concomitant peroneal nerve palsy. When other injury characteristics were assessed, there were no differences in PROMs for comparing patients with and without associated fractures, vascular injury, and knee dislocations.

Limitations

The present study has several limitations. First, being retrospective in nature this study is susceptible to both selection and attrition bias. To adjust for this, we provided an additional calculation of the failure rate accommodating patients who would have otherwise been excluded based on a lack of PROM data. Regardless, there are still patients that may not have been captured secondary to coding errors, or documentational mistakes. In addition, not all data points were readily available, like in the handful of patients who lacked documentation of varus stress widening measurements. Likewise, the majority of these injuries occurred from a high-energy mechanism that should be taken into consideration when applied to an athletic or ultra-low-energy trauma population. Second, this assessment was conducted at a single surgeon's practice. The generalizability of these findings is outside the indications and setting described in this study and are unclear.

Another limitation is that the quantitative assessment of lateral joint space widening was determined by palpating the lateral joint while stressing the knee. Any bias or subjectivity potentially imparted during these assessments could have been mitigated by performing radiographic stress films. However, the patients in this report had relatively low activity levels during the postoperative period and may not have "stressed" the lateral side of the knee with daily activities. It is unclear to whether the precision of radiographic diagnosis and measurement is truly clinically necessary if a knee does not exhibit any signs or symptoms of varus instability elsewhere. In addition, as final radiographs were not obtained, we are unable to report any incidence of medial compartment osteoarthritic changes which may be a subtle sign of PLC laxity.

CONCLUSION

Repair of acute grade 3 combined PLC avulsion injuries using a transosseous Krackow suture pull-through technique demonstrated a failure rate of 10.7%. Patients who underwent a staged cruciate reconstruction(s) had higher subjective outcome scores than those who had cruciate injuries left untreated. Peroneal nerve injury was associated with lower outcome scores. Surgical repair of PLC avulsion injuries using the proposed technique is best utilized acutely and in those without evidence of midsubstance injuries.

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APPENDIX

TABLE A1
The 7 Excluded Patients Provide Information Regarding Injury Classification, Reason for Exclusion, Physical Exam Findings, Special Notes to Consider for the Patients, and any Reoperations[a]

Patient	Cruciate Injury	Cruciate Procedure	Reason for Exclusion	Final Follow-up, mo	Widening on Varus Examination[b]	Subjective instability	Lachman Grade	Note	Reoperation
1	ACL+ PCL	No	No PROMs	75.2	Symmetric	No	1B	Arthrofibrosprecluded initial bi-cruciate reconstruction. Not pursued later due to lack of subjective instability	No
2	ACL	No	No PROMs	24.8	Extension: 0 mm 30°: 3 mm	No	2B	For social reasons could not undergo recommended ACLR	No
3	ACL avulsion + PCL	Acute ACL avulsion ORIF + PCL recon	No PROMs	25.5	Symmetric	No	0	—	No
4	ACL	No	No PROMs, <2-y follow-up	9.5	Extension: 0 mm 30°: 6 mm	No	2B	Prolonged recovery from of other injuries and disability from foot drop precluded ACLR	No
5	ACL	No	No PROMs, <2-y follow-up	12.2	Extension: 3 mm 30°: 6 mm	No	2B	Noncompliant with sporadic follow-up, substantial disability from foot drop, ACLR not performed secondary to concerns about compliance/follow-up	No
6	ACL + PCL avulsion	Simultaneous ORIF of PCL avulsion with PLC repair	No PROMs, <2-y follow-up	21.8	Symmetric	No	1B	ACLR precluded by arthrofibrosis, without subjective instability on resolution	No
7	ACL+ PCL	No	No PROMs, <2-y follow-up	9.6	Extension: 0 mm 30°: 3 mm	Sagittal plane instability	2B	Severe preexisting osteoarthritis that precluded bi-cruciate reconstruction	TKA 26 mo after injury

[a]ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; ORIF, open reduction and internal fixation; PCL, posterior cruciate ligament; PLC, posterolateral corner; PROM, patient-reported outcome measure; TKA, total knee arthroplasty.
[b]Compared to the contralateral knee.