A Biomechanical Comparison of the Arciero and LaPrade Reconstruction for Posterolateral Corner Knee Injuries

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Background: Injury to the posterolateral corner (PLC) of the knee requires reconstruction to restore coronal and rotary stability. Two commonly used procedures are the Arciero reconstruction technique (ART) and the LaPrade reconstruction technique (LRT). To the authors' knowledge, these techniques have not been biomechanically compared against one another.

Purpose: To identify if one of these reconstruction techniques better restores stability to a PLC-deficient knee and if concomitant injury to the proximal tibiofibular joint or anterior cruciate ligament affects these results.

Study Design: Controlled laboratory study.

Methods: Eight matched-paired cadaveric specimens from the midfemur to toes were used. Each specimen was tested in 4 phases: intact PLC (phase 1), PLC sectioned (phase 2), PLC reconstructed (ART or LRT) (phase 3), and tibiofibular (phase 4A) or anterior cruciate ligament (phase 4B) sectioning with PLC reconstructed. Varus angulation and external rotation at 0°, 20°, 30°, 60°, and 90° of knee flexion were quantified at each phase.

Results: In phase 3, both reconstructions were effective at restoring laxity back to the intact state. However, in phase 4A, both reconstructions were ineffective at stabilizing the joint owing to tibiofibular instability. In phase 4B, both reconstructions had the potential to restrict varus angulation motion. There were no statistically significant differences found between reconstruction techniques for varus angulation or external rotation at any degree of flexion in phase 3 or 4.

Conclusion: The LRT and ART are equally effective at restoring stability to knees with PLC injuries. Neither reconstruction technique fully restores stability to knees with combined PLC and proximal tibiofibular joint injuries.

Clinical Relevance: Given these findings, surgeons may select their reconstruction technique based on their experience and training and the specific needs of their patients.

Keywords: posterolateral corner; knee; reconstruction; multiligament injury

The posterolateral corner (PLC) of the knee consists of multiple static and dynamic components, including the fibular collateral ligament (FCL), popliteus tendon (PLT), popliteofibular ligament (PFL), lateral gastrocnemius tendon, iliotibial band, and biceps femoris tendon. Research has demonstrated that the primary stabilizers of the PLC consist of the FCL, PLT, and PFL, and some or all of these structures have been the target of many reconstruction strategies.[5,20,25] The PLC structures stabilize the knee at varying degrees of flexion by resisting varus angulation (VA) and external rotation (ER).

Injury to the PLC can increase VA, ER, and posterior tibial translation. Although isolated injuries to the PLC may be treated nonoperatively, they frequently present in conjunction with injury to one or both cruciate ligaments or to the proximal tibiofibular (tib-fib) joint, and in those situations, an operative approach is recommended.[7] Surgical strategies may include repair, reconstruction, or a combination thereof, depending on the chronicity and severity of the injury to the PLC. Given the complex anatomy and variable injury patterns, several PLC reconstructive procedures have been proposed, including biceps tenodesis, fibula-based reconstructions, and combined tibia and fibula–based reconstructions. Previous studies have compared several of these options.[8,9,11,12,21,22,27]

In 2004, LaPrade et al[16] published their biomechanical results based on an anatomic reconstruction of the PLC in 10 human cadaveric specimens. The anatomic locations of the FCL, PLT, and PFL were reconstructed with a combined tibia and fibula–based technique with 2 free Achilles

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allograft tendons. The results of their study demonstrated no significant difference between the intact and reconstructed knees with respect to varus translation or ER at any flexion angle. In 2005, Arciero[1] published a technique in which the PLC was reconstructed with a fibular-based free soft tissue graft. The author noted in a clinical series that this reconstruction technique predictably restored VA and ER stability. To date, these techniques have not been compared with each other to evaluate their effectiveness in restoring stability to a PLC-deficient knee. Further investigation has also shown that stability of the proximal tib-fib joint plays a role in PLC repair and reconstruction outcomes.[10]

At our institution, patients with PLC deficiency undergo reconstruction with one of these 2 options, and discussions among our surgeons have raised the question of whether the LaPrade reconstruction technique (LRT) or the Arciero reconstruction technique (ART) is more effective in restoring patholaxity from these injuries. This study was designed and performed to answer this question and to assess whether reconstruction stability might be affected by proximal tib-fib instability or more dependent on an intact anterior cruciate ligament (ACL). Our hypothesis was that there would be no differences in the ability of the 2 reconstruction techniques to restore stability in ER and VA.

METHODS

Eight pairs of male, fresh-frozen knees (16 knees) from the midfemur to toe (mean age, 78.8 years; range, 55-95 years; Science Care Inc) that were free of visible knee pathology were purchased for use in this study. Prior to testing, the specimens were thawed at room temperature twice: once to perform specimen preparation and to harvest grafts for reconstruction and a second time to perform the reconstructions and testing. A senior orthopaedic surgical resident (P.J.J.) harvested the semitendinosus, gracilis, and Achilles tendons from each specimen to use as grafts for the corresponding reconstructions. The foot was disarticulated, exposing the articular surface of the distal tibia, and the skin and subcutaneous fat were removed. The knees and grafts were kept moist with saline throughout the testing procedure.

PLC Reconstruction Techniques

All dissections, sectioning, and reconstructions were performed by a sports medicine fellowship–trained orthopaedic surgeon experienced in multiligament reconstruction and familiar with both reconstruction techniques (G.P.T.). All tunnels were created with a cannulated reamer over a guide pin that was placed with described anatomic landmarks. Prior to fixation, all grafts were manually tensioned in the manner replicating the technique used during operative PLC reconstructions in our practice. All implants and No. 2 polyethelene core sutures used in the reconstructions were manufactured and donated by a single company (Arthrex).

The ART was completed as described by Arciero.[1] A free semitendinosus graft was used for the reconstruction. Whipstitches were placed in each end of the graft to aid in graft passage. After identification of the femoral insertion sites, a 7 × 25–mm socket was created for the PLT and a 7 × 50–mm socket was created for the FCL. The fibular insertion sites of the FCL and PFL were identified, and a 7-mm tunnel was created from distal lateral to proximal medial through the fibular head to ensure adequate surrounding bone stock. One end of the graft was passed into the PLT socket and fixed with an 8 × 23–mm polyether ether ketone (PEEK) biotenodesis interference screw. The graft was then passed through the fibular tunnel from posterior to anterior and tensioned with the knee at 60° of flexion, neutral rotation, and a valgus stress applied. The graft was fixed in the fibular tunnel with a 7 × 23–mm PEEK screw. The graft was then passed into the FCL femoral insertion with a pull-through technique. The graft was tensioned with the knee at 30° of flexion, neutral rotation, and a valgus stress applied. The graft was finally secured with an 8 × 23–mm PEEK interference screw.

The LRT was completed as described by LaPrade et al.[16] A split Achilles graft with 9 × 20–mm bone plugs was used for the reconstruction. A whipstitch was placed in the proximal end of each graft to aid in passage. Similar to the ART technique, the femoral insertion sites for the PLT and FCL were identified, and a 9 × 25–mm socket was created at each site. Likewise, a 7-mm fibular tunnel was created through the FCL insertion, exiting posteromedially on the fibular head. Finally, a 10 mm–diameter tibial tunnel was created, originating between the Gerdy tubercle and the

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Ethical approval was not sought for the present study.

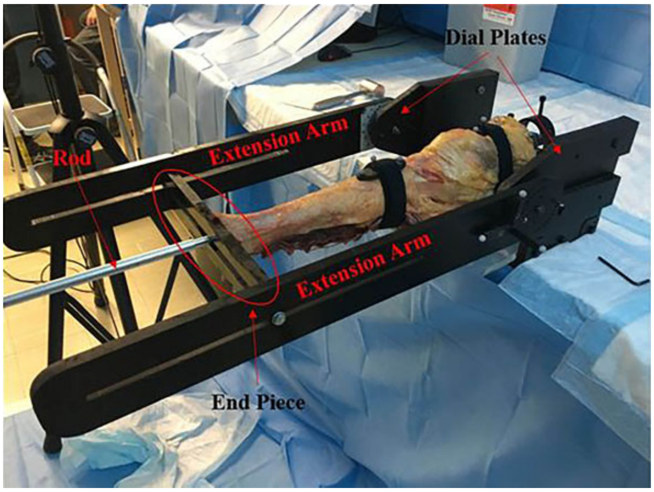

Figure 1. Custom test fixture design to apply varus moments and rotational torque to measure varus angulation and external rotation about the knee, respectively. The dial plates enabled controlled knee flexion angles for each test. The extension arms allowed for patient-specific adjustment of length. The end piece enabled controlled varus and torsional loading. The force gauge and torque wrench were attached to the rod for force and torque measurement, respectively.

tibial tubercle anteriorly and exiting in the popliteal sulcus on the posterior tibia slightly medial and proximal to the medial fibular tunnel aperture. Each bone plug was secured in its respective femoral socket with a 7 × 20–mm titanium interference screw. The PLT graft was passed along the course of the native PLT and into the tibial tunnel. The FCL graft was passed along the FCL native course and through the fibular tunnel. The knee was placed at 30° of flexion, neutral rotation, and valgus while the graft was tensioned and fixed in the fibular tunnel with a 7 × 23–mm PEEK screw. The FCL graft was then passed through the tibial tunnel. The 2 grafts were then tensioned with the knee in 60° of flexion, neutral rotation, and a valgus stress applied. The grafts were finally secured with an 11 × 28–mm PEEK screw placed anterior to posterior.

Mechanical Testing

A custom testing fixture (Figure 1) was fabricated that allowed mounting of the specimens at 0°, 20°, 30°, 60°, and 90° of knee flexion. The femur was rigidly fixed to the testing apparatus.[6] An intramedullary rod was rigidly fixed at the distal tibia and the specimen was secured after alignment of the knee joint with the flexion axis of the fixture. A digital force gauge (FG-3008; Nidec-Shimpo) was used to apply a varus force perpendicular to the long axis of the rod. A 10-N·m varus moment was applied by measuring the length of the moment arm (knee joint to force gauge) and calculating the appropriate force needed to create a 10-N·m moment. A torque wrench attached to the intramedullary rod was used to manually apply a 5-N·m ER torque about the long axis of the rod.

Data Acquisition

Eight OptiTrack motion capture cameras (Prime 13 cameras, Natural Point Inc) were used to quantify VA and ER angular displacement about the knee. This was done with the use of rigid body marker sets placed on the tibial tuberosity, the anterior aspect of the femur (5 cm proximal from the knee joint), and the outside arm of the testing fixture located adjacent to its point of rotation. Motion capture software (Motive:Body; Natural Point Inc) recorded the initial and final positions of the marker sets. Custom Matlab software (MathWorks) was written to transform the data from a global coordinate system to a local coordinate system defined by the knee anatomy. Measurements were taken with no load, after application of a 10-N·m varus moment, and after application of a 5-N·m external tibial torque. After biomechanical testing in the intact state (phase 1), subsequent testing was performed after 3 sequential interventions: sectioning of the FCL, PFL, and PT (phase 2); PLC reconstruction (phase 3); and further sectioning of the proximal tib-fib joint (phase 4A) or the ACL (phase 4B). Four matched pairs had the proximal tib-fib joint sectioned, and 4 had the ACL sectioned. For every matched pair, 1 leg was randomized to the ART, while the contralateral limb underwent the LRT.

Data Analysis

Multivariate analysis of variance was used through the SAS system (SAS/STAT v 14.2, SAS Institute) to assess the mean differences over the 5 knee flexion angles between each phase (2, 3, and 4) and the intact state (phase 1), as well as between the ART and LRT reconstruction groups for each phase. The Wilks lambda statistic and a significance level of 5% were used to determine statistical differences. A post hoc parallel profile test was conducted to investigate if the 2 reconstruction profiles showed parallelism or a consistent difference across all flexion angles.

Second, an aggregate total of paired assessments was performed to detect if the ART or LRT technique more closely approximated intact stability for each knee in phase 3 and phase 4 in terms of percentage recovered ER or VA at post-reconstruction. The mean value for each specimen pair was compared at each flexion angle to identify which reconstruction most closely restored ER and VA to the intact state.

RESULTS

No statistical difference was found between the ER and VA data for the paired knees in an intact state ($P = .57$ and .77, respectively). This indicated no physiologic concerns in the specimens that might affect outcome data. It also allowed us to combine and establish baseline intact ER and VA profiles with the ART and LRT specimens at phases 1 and 2 of the study. After sectioning of the posterolateral structures (phase 2), there was a significant increase in ER ($P <$ .0001) and VA ($P = .02$) laxity at all flexion angles. After PLC reconstruction (phase 3), there was no significant

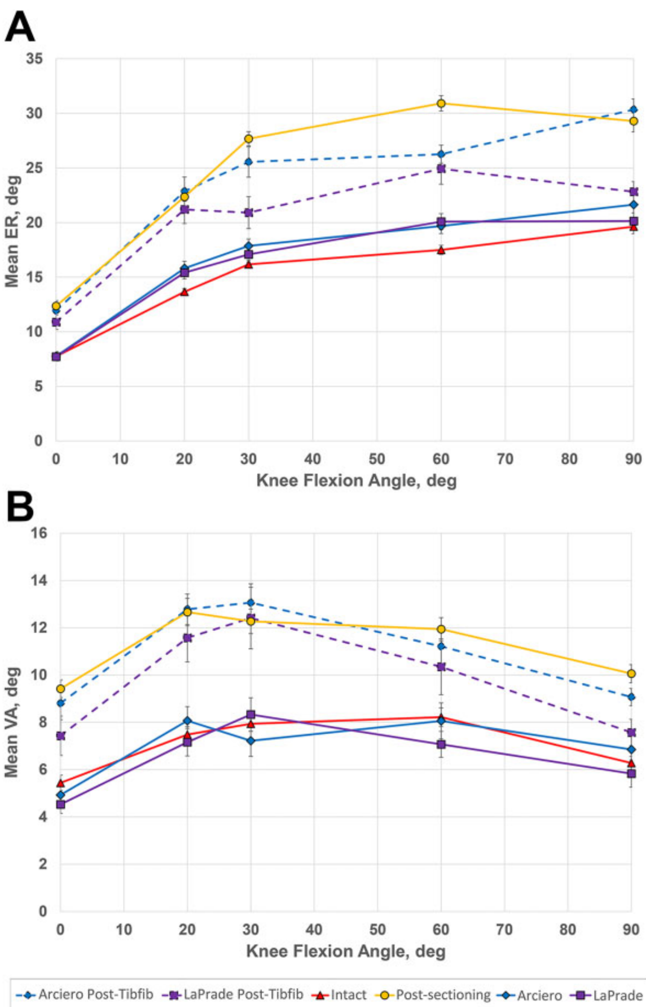

Figure 2. (A) ER and (B) VA data for intact, post–PLC sectioning, post–PLC reconstruction (ART or LRT), and post–tib-fib sectioning. The graph depicts mean values and 95% CIs for each data set at each knee flexion angle. After tib-fib sectioning, both reconstructions exhibited laxity to the knee at or near the post–PLC sectioning unreconstructed state. Red, intact; blue, ART; purple, LRT; yellow, post–PLC sectioning. ART, Arciero reconstruction technique; ER, external rotation; LRT, LaPrade reconstruction technique; PLC, posterolateral corner; tib-fib, tibiofibular; VA, varus angulation.

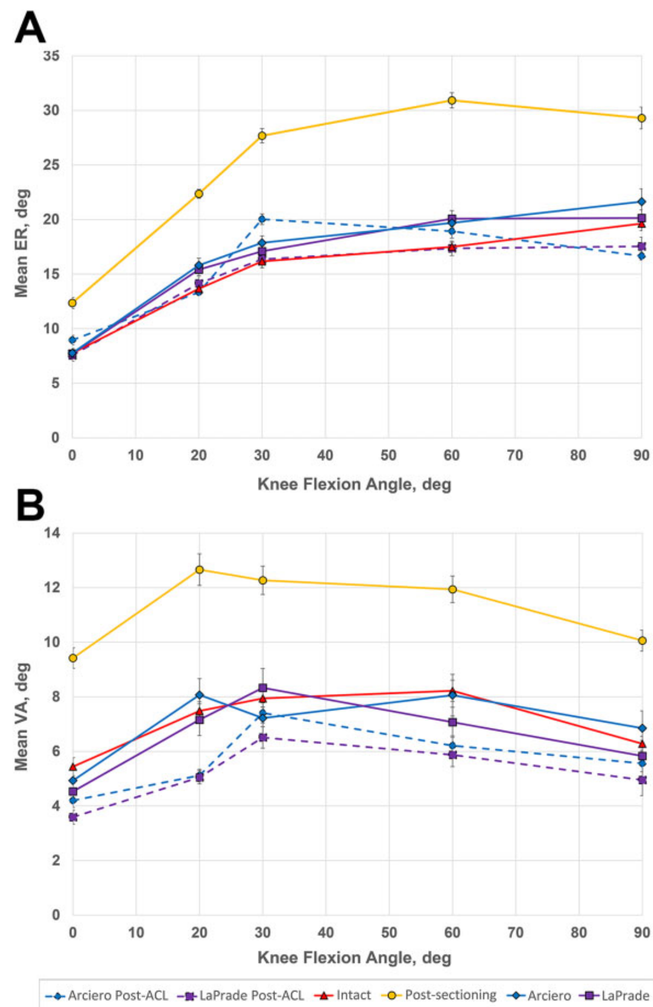

Figure 3. (A) ER and (B) VA data for intact, post–PLC sectioning, post–PLC reconstruction (ART or LRT), and post–ACL sectioning. The graph depicts mean values and 95% CIs for each data set at each knee flexion angle. After ACL sectioning, there was no effect on ER, but VA stability increased beyond the intact state. Red, intact; blue, ART; purple, LRT; yellow, post–PLC sectioning. ACL, anterior cruciate ligament; ART, Arciero reconstruction technique; ER, external rotation; LRT, LaPrade reconstruction technique; PLC, posterolateral corner; tib-fib, tibiofibular; VA, varus angulation.

difference in ER or VA laxity between the ART ($P = .51$) or LRT ($P = .69$) and the intact state. There was no significant difference between the ART and the LRT for either ER ($P = .48$) or VA ($P = .72$).

After sectioning of the proximal tib-fib joint (phase 4A), both reconstructions demonstrated increased laxity to the knee to a level near their post-sectioning, unreconstructed state. A comparison between ART and LRT data showed no statistical difference in ER ($P = .23$) or VA ($P = .18$) after tib-fib sectioning (Figure 2). After sectioning of the ACL (phase 4B), there was no significant difference in ER ($P = .85$) or VA ($P = .20$) laxity (Figure 3). ACL sectioning had no effect on ER but increased the VA stability of the knee beyond the intact state of the specimens.

A post hoc parallel profile test showed that the 2 techniques displayed parallelism for VA measures after tib-fib sectioning (phase 4A, $P = .99$). The LRT technique was able to restore stability near intact values more frequently than the ART technique for ER and VA (Table 1).

DISCUSSION

The importance of the PLC in knee function has been well established, and a thorough evaluation of these

TABLE 1
Recovery of External Rotation and Varus Angulation in the LaPrade and Arciero Reconstructions[a]

	Post–PLC Reconstruction		Post–Tibiofibular Sectioning		Post–ACL Sectioning		Total	
Knee Flexion Angle	LRT	ART	LRT	ART	LRT	ART	LRT	ART
External rotation recovery								
0°	5	3	1	3	4	0	10	6
20°	5	3	3	1	2	2	10	6
30°	5	3	2	2	4	0	11	5
60°	3	5	2	2	3	1	8	8
90°	3	5	2	2	3	1	8	8
Varus angulation recovery								
0°	5	3	4	0	3	1	12	4
20°	7	1	3	1	1	3	11	5
30°	2	6	4	0	4	0	10	6
60°	5	3	3	1	2	2	10	6
90°	7	1	3	1	1	3	11	5

[a]Values are presented as the number of LRT and ART reconstructions with restoration of stability closer to the intact state at each knee flexion angle for external rotation (top) and varus angulation (bottom) when matched pairs were compared. Sixteen tests were evaluated. ACL, anterior cruciate ligament; ART, Arciero reconstruction technique; LRT, LaPrade reconstruction technique; PLC, posterolateral corner.

structures in the context of knee ligament injuries is necessary to fully treat all patholaxity. Unrecognized or undertreated PLC injuries may compromise patient outcomes after reconstruction of other knee ligaments and may increase failure rates of these interventions.[2] Given this importance, the PLC has been the subject of study regarding its anatomy and biomechanical properties as well as imaging characteristics.[3,12,13,15,17-19,23,26] This knowledge has influenced our recognition of and treatment strategies for these injuries.

Acutely injured structures have been historically treated with repair, reconstruction, or a combination thereof. In a clinical series of 63 patients with PLC injuries, Stannard et al[24] demonstrated that reconstruction of the PLC performed superiorly to repair alone and recommended reconstruction in most cases. These findings demonstrate the importance of robust, functional, and anatomic reconstruction, although the most effective reconstruction method has not been fully defined. Reconstruction options have been described and various techniques explored and compared by many authors.[¶]

While no direct comparison of the ART and the LRT has been completed, several cadaveric biomechanical studies have compared various other surgical techniques to address PLC injuries. Rauh et al[22] tested 10 knee pairs reconstructed with a fibular- or combined tibia and fibula–based reconstruction with a free tendon graft. Knees were tested at 30° and 90° of flexion, and both reconstructions were found to restore ER and VA values to near the intact state. Ho et al[9] evaluated the effect of 1 versus 2 femoral tunnels as part of a fibular-based reconstruction in 5 knees. They found that both techniques improved ER and posterior tibial translation, although the 2-tunnel technique was superior. Kanamori et al[11] studied a PFL reconstruction technique as compared with biceps tenodesis in 10 knees. They reported that the PFL technique better restored ER and posterior tibial translation. Finally, Nau et al[21] compared 2 PLC reconstructions with a fibula- or tibia and fibula–based technique in 10 knees. While the study was an evaluation of these 2 techniques, the authors opted to transect the fibula just below the neck and stabilize the proximal tib-fib joint with a screw. These decisions may have introduced a different biomechanical environment than the one in our model, where the tibia and fibula were left intact down to the ankle. Nau et al[21] noted that both techniques restored ER and VA to near normal but that the tibia and fibula–based technique created abnormal internal rotation values from 0° to 90° of flexion. The authors postulated that the reconstruction of the PLT portion of the PLC resulted in these findings, as it introduced a nonisometric static restraint where a dynamic restraint typically functions in a normal knee.

At our institution, the ART and LRT are most commonly used among patients with PLC injuries. Debate persists regarding the need to reconstruct the FCL, PLT, and PFL independently and whether a reconstruction based solely on the fibula is adequate or if a combined tibia and fibula–based reconstruction is required to maximize knee stability. Potential advantages of the ART include less dissection, fewer tunnels and implants, and less risk to the posterior neurovascular structures. Proposed advantages of the LRT include additional collagen bundles in the reconstruction, improved stability with tibia and fibula joint instability, and a more anatomic approximation of the route of the PLT. Our goal was to assess the ability of these 2 techniques to restore PLC function, in an attempt to best choose surgical treatments for our patients.

In our study, we found that intact testing and post-sectioning of the matched-paired specimens showed no differences in their ER and VA profiles. At post-reconstruction, the ART and LRT both successfully returned stability of the PLC to near-intact conditions. The

[¶]References 1, 4, 8, 9, 11, 14, 16, 21, 22, 27 most apparent increase in laxity occurred at the post–tib-fib sectioning phase. In this scenario, stability parameters were similar to the post-sectioning, unreconstructed state for both the ART and the LRT. This supports the findings of Jabara et al[10] in that a deficient proximal tib-fib joint compromises the integrity of the PLC and may result in failure of the reconstruction. The finding suggests that the proximal tib-fib joint should be stabilized in these situations to maximize the effectiveness of PLC reconstruction. A positive post hoc parallel profile test for VA after tib-fib sectioning indicated that a larger sample size may have elucidated a statistical difference between the techniques. This is not likely clinically important, however, since neither reconstruction was effective at restoring stability in this situation. It is important to note that after ACL sectioning, both techniques have the potential to restrict motion of the joint in VA. This becomes important clinically in situations where the PLC is reconstructed prior to final tensioning and fixation of an ACL graft.

In the evaluation of the aggregate total of counts in which either technique was better at approximating intact stability, the LRT technique was consistently closer to intact ER and VA measures than the ART at all flexion angles. According to multivariate analysis of variance, the outcome measure of this study had a medium effect size, f^2(V), equal to 0.20. Based on this number, a sample size of 35 matched pairs would be needed to elucidate a difference between the techniques at the 5% significance level and 80% power.

Our study has several limitations. The first relates to the cadaveric nature of the study; however, a matched-paired study offers the best in vitro method of comparison. Second, this is a time-zero study and does not evaluate the effect of repetitive load and motion on the 2 reconstructions. Perhaps one of the reconstructions would perform better under these conditions. Similarly, PLC reconstructions are nearly always performed with other ligament reconstructions, and one of these techniques might perform better in that scenario. Additionally, the effect of graft healing and incorporation was not studied. The specimens used had a mean age of 78 years, which is older than our typical patient population treated with PLC reconstruction. Finally, this study may have been underpowered to detect a difference in the two reconstructions.

The study was designed similar to other studies in the literature, and with the exception of the study by Rauh et al,[22] it exceeded the number of specimens utilized in all of the other cited comparative studies as well as the original descriptive study by LaPrade et al.[16] However, as these studies did not have a power analysis performed, they could not be used to assess power in the current study design. Alternatively, a pilot study could have been performed to determine power, but this option provided substantial additional financial obstacles that could not be resolved. A post hoc analysis demonstrated that with the addition of more specimens, a difference may have been seen in the data. While a study with this large number of specimens is possible, it presents considerable logistical and financial limitations while providing little clinical relevance to the small differences that might be found.

CONCLUSION

We can conclude that no statistical difference was found in the ability to restore ER and VA stability between the ART and LRT, although the study may have been underpowered according to post hoc analysis. We recommend that surgeons select their technique based on preference, training, and patient-specific scenarios, with less concern for surgical outcomes affecting PLC stability.

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REFERENCES

1. Arciero RA. Anatomic posterolateral corner knee reconstruction. *Arthroscopy*. 2005;21(9):1147.
2. Bolog N, Hodler J. MR imaging of the posterolateral corner of the knee. *Skeletal Radiol*. 2007;36(8):715-728.
3. Cooper JM, McAndrews PT, LaPrade RF. Posterolateral corner injuries of the knee: anatomy, diagnosis, and treatment. *Sports Med Arthrosc*. 2006;14(4):213-220.
4. Davies H, Unwin A, Aichroth P. The posterolateral corner of the knee: anatomy, biomechanics and management of injuries. *Injury*. 2004; 35(1):68-75.
5. Djian P. Posterolateral knee reconstruction. *Orthop Traumatol Surg Res*. 2015;101(1):S159-S170.
6. Engebretsen L, Wijdicks CA, Anderson CJ, Westerhaus B, LaPrade RF. Evaluation of a simulated pivot shift test: a biomechanical study. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(4):698-702.
7. Fanelli GC, Edson CJ. Combined posterior cruciate ligament-posterolateral reconstructions with Achilles tendon allograft and biceps femoris tendon tenodesis: 2- to 10-year follow-up. *Arthroscopy*. 2004;20(4):339-345.
8. Geeslin AG, LaPrade RF. Outcomes of treatment of acute grade-III isolated and combined posterolateral knee injuries: a prospective case series and surgical technique. *J Bone Joint Surg Am*. 2011; 93(18):1672-1683.
9. Ho EP, Lam MH, Chung MM, et al. Comparison of 2 surgical techniques for reconstructing posterolateral corner of the knee: a cadaveric study evaluated by navigation system. *Arthroscopy*. 2011;27(1): 89-96.
10. Jabara M, Bradley J, Merrick M. Is stability of the proximal tibiofibular joint important in the multiligament-injured knee? *Clin Orthop Relat Res*. 2014;472(9):2691-2697.
11. Kanamori A, Lee JM, Haemmerle MJ, Vogrin TM, Harner CD. A biomechanical analysis of two reconstructive approaches to the posterolateral corner of the knee. *Knee Surg Sports Traumatol Arthrosc*. 2003;11(5):312-317.
12. Kim YH, Purevsuren T, Kim K, Oh KJ. Contribution of posterolateral corner structures to knee joint translational and rotational stabilities: a computational study. *Proc Inst Mech Eng H*. 2013;227(9):968-975.
13. LaPrade RF, Bollom TS, Wentorf FA, Wills NJ, Meister K. Mechanical properties of the posterolateral structures of the knee. *Am J Sports Med*. 2005;33(9):1386-1391.
14. Laprade RF, Griffith CJ, Coobs BR, Geeslin AG, Johansen S, Engebretsen L. Improving outcomes for posterolateral knee injuries. *J Orthop Res*. 2014;32(4):485-491.
15. LaPrade RF, Heikes C, Bakker AJ, Jakobsen RB. The reproducibility and repeatability of varus stress radiographs in the assessment of isolated fibular collateral ligament and grade-III posterolateral knee injuries: an in vitro biomechanical study. *J Bone Joint Surg Am*. 2008; 90(10):2069-2076.

16. LaPrade RF, Johansen S, Wentorf FA, Engebretsen L, Esterberg JL, Tso A. An analysis of an anatomical posterolateral knee reconstruction: an in vitro biomechanical study and development of a surgical technique. *Am J Sports Med*. 2004;32(6): 1405-1414.
17. LaPrade RF, Ly TV, Wentorf FA, Engebretsen L. The posterolateral attachments of the knee: a qualitative and quantitative morphologic analysis of the fibular collateral ligament, popliteus tendon, popliteofibular ligament, and lateral gastrocnemius tendon. *Am J Sports Med*. 2003;31(6):854-860.
18. LaPrade RF, Morgan PM, Wentorf FA, Johansen S, Engebretsen L. The anatomy of the posterior aspect of the knee: an anatomic study. *J Bone Joint Surg Am*. 2007;89(4):758-764.
19. Lunden JB, Bzdusek PJ, Monson JK, Malcomson KW, Laprade RF. Current concepts in the recognition and treatment of posterolateral corner injuries of the knee. *J Orthop Sports Phys Ther*. 2010;40(8): 502-516.
20. McCarthy M, Camarda L, Wijdicks CA, Johansen S, Engebretsen L, Laprade RF. Anatomic posterolateral knee reconstructions require a popliteofibular ligament reconstruction through a tibial tunnel. *Am J Sports Med*. 2010;38(8):1674-1681.
21. Nau T, Chevalier Y, Hagemeister N, Deguise JA, Duval N. Comparison of 2 surgical techniques of posterolateral corner reconstruction of the knee. *Am J Sports Med*. 2005;33(12):1838-1845.
22. Rauh PB, Clancy WG Jr, Jasper LE, Curl LA, Belkoff S, Moorman CT 3rd. Biomechanical evaluation of two reconstruction techniques for posterolateral instability of the knee. *J Bone Joint Surg Br*. 2010; 92(10):1460-1465.
23. Sanchez AR 2nd, Sugalski MT, LaPrade RF. Anatomy and biomechanics of the lateral side of the knee. *Sports Med Arthrosc*. 2006; 14(1):2-11.
24. Stannard JP, Brown SL, Farris RC, McGwin G Jr, Volgas DA. The posterolateral corner of the knee: repair versus reconstruction. *Am J Sports Med*. 2005;33(6):881-888.
25. Terry GC, LaPrade RF. The posterolateral aspect of the knee: anatomy and surgical approach. *Am J Sports Med*. 1996;24(6):732-739.
26. Vinson EN, Major NM, Helms CA. The posterolateral corner of the knee. *AJR Am J Roentgenol*. 2008;190:449-458.
27. Yoon KH, Lee JH, Bae DK, Song SJ, Chung KY, Park YW. Comparison of clinical results of anatomic posterolateral corner reconstruction for posterolateral rotatory instability of the knee with or without popliteal tendon reconstruction. *Am J Sports Med*. 2011;39(11):2421-2428.