Posterior Tibial Translation Measurements on Magnetic Resonance Imaging Improve Diagnostic Sensitivity for Chronic Posterior Cruciate Ligament Injuries and Graft Tears

Nicholas N. DePhillipo,* MS, ATC, OTC, Mark E. Cinque,† BS, Jonathan A. Godin,† MD, MBA, Gilbert Moatshe,† MD, Jorge Chahla,† MD, PhD, and Robert F. LaPrade,*†‡ MD, PhD
Investigation performed at The Steadman Clinic, Vail, Colorado, USA

Background: Magnetic resonance imaging (MRI) of the knee is a highly sensitive and specific method for diagnosing acute posterior cruciate ligament (PCL) tears, with a reported accuracy of 96% to 100%. In chronic and revision settings, these injuries may be missed on MRI because of the apparent continuity of nonfunctional PCL fibers. Posterior tibial translation (PTT) of the medial compartment has been identified as a potential secondary finding of PCL tear on routine MRI.

Purpose/Hypothesis: The purpose of this study was to evaluate the sensitivity of PTT on MRI associated with PCL injuries and compare it with the sensitivity of a radiologist's MRI interpretation with preoperative posterior knee stress radiographs as the gold standard. Our hypothesis was that the MRI measurement of PTT of the medial compartment would improve diagnostic sensitivity as compared with the diagnosis made by the interpreting radiologist's evaluation of the continuity of the PCL fibers for chronic and postrecostruction graft injuries.

Study Design: Cohort study (diagnosis); Level of evidence, 2.

Methods: Cases of patients who underwent a primary or revision PCL reconstruction, without anterior cruciate ligament injury, by a single surgeon between 2010 and 2016 were retrospectively analyzed. Measurements of medial and lateral compartment PTT were performed with the MRI of PCL-injured cases and controls without clinical or MRI evidence of ligamentous injury. The sensitivity of this technique was compared with the preoperative MRI diagnosis determined by review of the musculoskeletal radiologist's report and confirmed by the gold standard of posterior knee stress radiographs. The sensitivity of medial compartment PTT was determined by receiver operator characteristic (ROC) analysis and compared with the MRI sensitivity for chronic PCL and PCL graft tears.

Results: One hundred patients (80 males and 20 females) with a mean age of 31.1 years (range, 15-66 years) met the inclusion criteria: 57 acute primary tears, 32 chronic primary, and 11 PCL graft tears. MRI sensitivity was 100% for acute primary PCL tears, 62.5% for chronic primary PCL tears, and 18.1% for PCL graft tears. There were significant differences in medial compartment PTT on MRI for acute versus chronic injuries ($P = .025$) and acute versus graft injuries ($P = .007$). ROC curve analysis indicated that the most accurate cutoff point for the detection of chronic PCL tears was 2.0 mm of medial compartment PTT on MRI, with a sensitivity and specificity of 0.80 and 0.89, respectively. For PCL graft injuries, the ROC curve indicated that the most accurate medial compartment PTT cutoff for the detection of PCL graft failure was 3.6 mm (sensitivity, 0.92; specificity, 0.72).

Conclusion: MRI evaluation of the PCL fibers had poor sensitivity for chronic PCL tears and PCL reconstruction graft tears. The sensitivity for diagnosing chronic PCL tears and PCL reconstruction graft failures was improved by measuring posteromedial tibial translation.

Keywords: posterior cruciate ligament; tibial translation; MRI; posterior knee instability

The posterior cruciate ligament (PCL) has an intrinsic ability to heal, and it may regain continuity of its fibers after an injury.[11,20] However, owing to gravitational forces and persistent posterior subluxation of the tibia during the recovery process after injury, the PCL may heal in an elongated position.[21,24] Healing of the PCL in an elongated position can lead to chronic laxity and subsequent degenerative changes of the knee joint.[21,23,25]

With inconclusive findings during the patient history and physical examination, physicians often rely on magnetic resonance imaging (MRI) to identify PCL tears. In

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this regard, MRI has been reported to be 96% to 100% sensitive for the detection of acute ($\leq$6 weeks) PCL tears.[5-7,17] In the setting of chronic (>6 weeks) PCL tears and PCL reconstruction graft tears, MRI may demonstrate continuity of the PCL fibers; however, the functionality of this tissue is difficult to discern. Because of these challenges, a secondary finding on MRI, such as increased posterior tibial translation (PTT) in the medial compartment, has been recognized as a potential tool for detecting a PCL tear.[4] Furthermore, posterior stress radiographs demonstrating >8 mm of PTT have been identified as the gold standard for the diagnosis of PCL tears.[10,22]

The correct diagnosis and surgical management of PCL tears are critical because PCL reconstruction produces more satisfactory and consistent stability when compared with nonoperative treatment in high-grade PCL injuries.[1,8,13,22,27] Although the body of literature on the treatment of PCL tears continues to grow, there is a relative paucity of literature on methods to improve the diagnosis of chronic PCL tears and reconstruction graft failure cases. Given this gap in the current literature, the purpose of this study was to evaluate the sensitivity of PTT on MRI associated with isolated and combined chronic and PCL reconstruction graft injuries and to compare it with the sensitivity of the MRI report with posterior knee stress radiographs as the gold standard.[10] In addition, clinical history and physical examination were used to define failure. Patients were considered to have a PCL graft failure if they reported pain/instability during deceleration and while going downstairs and if they had a positive posterior drawer test on examination. The hypothesis was that the MRI measurement of posteromedial tibial translation would improve the diagnostic sensitivity for PCL/graft tear when compared with the diagnosis made at the time of MRI by the interpreting musculoskeletal radiologist.

METHODS

Study Design

Following Institutional Review Board approval (protocol 2002-03), the cases of patients who underwent primary or revision PCL reconstruction between 2010 and 2016 by a single surgeon (R.F.L.) and had an available MRI were retrospectively analyzed. Inclusion criteria were defined as an isolated PCL tear with posterior stress radiographs, combined PCL–fibular collateral ligament tears with posterior and varus stress radiographs, PCL–medial collateral ligament tears with posterior and valgus stress radiographs, or combined PCL–posterolateral corner injury with posterior and varus stress radiographs—confirmed at the time of examination under anesthesia. Exclusion criteria included concomitant PCL and anterior cruciate ligament (ACL) tears and a prior osteotomy. In addition, patients in the PCL-injured cohort were not excluded for the presence of any nondisplaced meniscal tears or any full-thickness articular cartilage defects. However, patients were excluded if they had a bucket-handle meniscal tear, because the displacement from this tear could have an effect on sagittal plane tibial position. All patients were clinically examined preoperatively and underwent standardized preoperative imaging evaluation with plain and posterior knee stress radiographs and MRI. In addition, a control group was built to include patients without a clinical history and MRI evidence of ligamentous injury (ie, PCL, ACL, medial collateral ligament, or fibular collateral ligament). Controls were included if they had any other pathologic condition that was known to not affect tibial position in the sagittal plane on MRI, including but not limited to nondisplaced meniscal tears, full-thickness articular cartilage defects, or tendinopathy.

Imaging Evaluation

Posterior knee stress radiographs, clinical examination, examination under anesthesia, and arthroscopic procedures were reviewed to determine the presence of a PCL tear and concomitant injuries. The preoperative MRI report was reviewed to determine whether the interpreting musculoskeletal radiologist diagnosed a PCL tear, and the sensitivity was calculated. Additionally, 2 independent orthopaedic surgeons (J.C. and J.A.G.) evaluated the preoperative MRI of the PCL-injured group and the MRI of the control group to measure the amount of PTT in the midmedial and midlateral compartments according to a previously described technique (Figure 1).[4,9] The 2 orthopaedic surgeons measuring each MRI were independent, meaning not involved directly in the care of the included patients. This allowed the raters to be blinded to which patients were in the PCL-injured versus control group at the time of measuring the MRI. Measurements were made on sagittal proton density images. Tangential lines were drawn posterior to the femoral condyle and the posterior margin of the tibial plateau at the level of the midmedial and midlateral compartments. Perpendicular measurements of the relative anterior or posterior translation were made for each knee. Of note, anterior translation was recorded as a negative value. In addition, a new measurement technique was utilized through measurement of the amount of medial tibial compartment translation and comparison with the amount of lateral tibial compartment translation in the same knee. This value was used to show the normal amount of

[‡]Address correspondence to Robert F. LaPrade MD, PhD, Steadman Philippon Research Institute, The Steadman Clinic, 181 West Meadow Drive, Suite 400, Vail, CO 81657, USA (email: drlaprade@sprivail.org).

*The Steadman Clinic, Vail, Colorado, USA.

[†]Steadman Philippon Research Institute, Vail, Colorado, USA.

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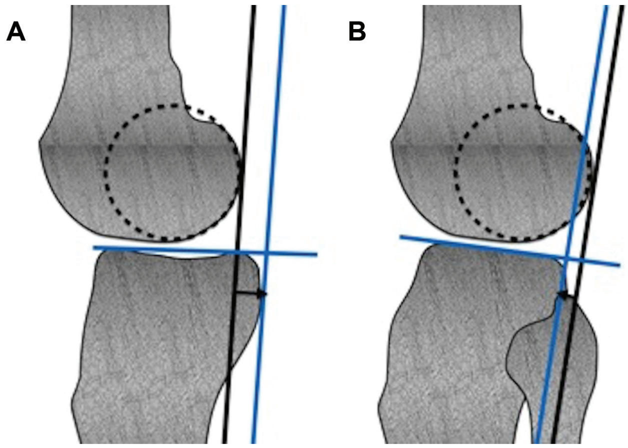

Figure 1. Schematic demonstrating a newly described measurement technique for posterior cruciate ligament–deficient knees on routine magnetic resonance imaging comparing the amount of (A) medial and (B) lateral compartment tibial translation, the difference of which was used for descriptive statistics only. A vertical line was drawn perpendicular to a tangential line drawn on the medial and lateral tibial plateaus, respectively. A circle was drawn with the best-fit circle tool on the posterior aspect of the femoral condyle, and a second vertical line was drawn parallel to the previously drawn line. Finally, the translation was measured between both vertical lines, and the difference between medial and lateral compartment tibial translation was utilized for analysis.

translation laterally and to determine if there was a difference in posterior translation medially (Figures 1 and 2).

Images were obtained with the knee near full extension and included MRI from 3.0-Tesla (n = 50) and 1.5-Tesla (n = 50) magnets. For the chronic primary cohort, 22 (68.7%) patients had MRI scans with 3.0-Tesla strength and 10 (31.2%) with 1.5-Tesla strength. For the revision cohort, 8 (72.7%) had MRI scans with 3.0-Tesla strength and 3 (27.2%) with 1.5-Tesla strength.

Statistical Analysis

Unpaired *t* tests were used to compare the mean posteromedial tibial translation and the mean difference between medial and lateral compartment tibial translation for the revision and chronic PCL groups versus the mean values in the control group. $P < .05$ was defined as statistical significance. Receiver operating characteristic (ROC) curves were built to identify the optimal cutoff point for posteromedial tibial translation for the revision and chronic PCL groups. Each data point on the ROC curve represented a cutoff point for a given amount of posterior translation, with an associated sensitivity and specificity value. The data point on the curve closest to the upper left corner of the graph represented the cutoff value with the greatest sensitivity and specificity. The overall diagnostic power of posteromedial translation measurement was assessed by reporting the area under the ROC curve (AUROC).

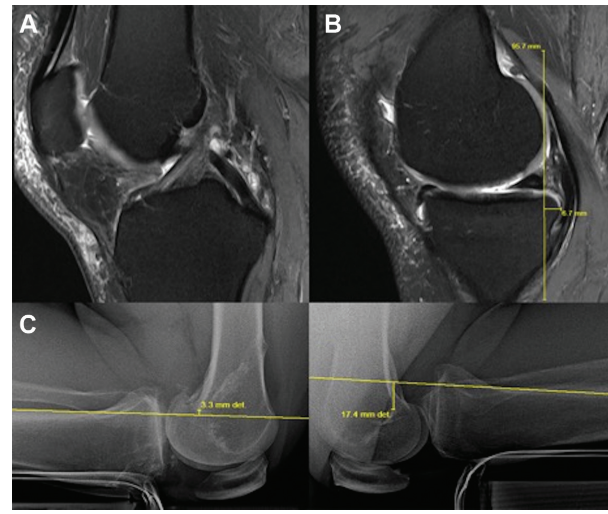

Figure 2. Secondary signs of a chronic posterior cruciate ligament (PCL) tear and a nonfunctional PCL graft tear (same concept applies to revision PCL cases). (A) Sagittal proton density fat-saturated T2-weighted magnetic resonance imaging showing continuity of the PCL in a patient with a chronic PCL injury. However, (B) PCL insufficiency/tear with 6.7 mm of posteromedial tibial translation demonstrates the residual laxity of the joint. (C) Confirmation of PCL laxity is performed with kneeling stress radiographs showing 14.1 mm of increased posteromedial tibial as compared with the uninjured contralateral limb.

RESULTS

Patient Demographics

Patient demographics for the injured and control cohorts are presented in Table 1. One hundred patients met the inclusion criteria. The PCL injury cohort included 89 primary and 11 revision PCL reconstruction cases, while the control group consisted of 100 patients without ligamentous injuries. Each patient with a PCL tear underwent an arthroscopic double-bundle reconstruction technique as previously described.[3,22] Of the primary PCL cohort, 57 cases were acute ($\leq$6 weeks) and 32 were chronic ($>$6 weeks) at the time of MRI. The mean time from injury to PCL reconstruction was 2.6 $\pm$ 1.4 and 72.5 $\pm$ 85.1 weeks for patients with acute and chronic tears, respectively. Posterior stress radiographs were performed in 87 of the 100 total patients. Thirteen patients with acute PCL tears did not have posterior stress radiographs, owing to having either an acute injury or a concomitant fracture that precluded weightbearing. However, the lack of stress radiographs did not affect the diagnosis of the PCL tear, because all acute tears were correctly diagnosed on clinical examination and MRI. The mean preoperative PTT on stress radiographs was 8.7 $\pm$ 2.4 mm for isolated PCL tears and 11.9 $\pm$ 3.4 mm for combined PCL tears and other grade 3 ligamentous injuries (posteromedial and posterolateral).

Sixty-six patients had combined ligament injuries with the PCL tear, while isolated PCL tears were identified in

TABLE 1
Demographics and Clinical Characteristics of the Patients With PCL Injuries[a]

	Total	Male	Female
Clinical characteristics			
Patients	100	80	20
Age, y	31.1 ± 12.6	30.1 ± 12.2	33.5 ± 13.0
BMI, kg/m^2	25.2 ± 4.1	26.0 ± 4.4	23.5 ± 4.8
Isolated PCL tear	34	27	7
Combined injury	66	53	13
Chronic PCL tears			
Patients	32	23	9
Age, y	30.6 ± 12.4	30.0 ± 12.3	32.9 ± 13.0
BMI, kg/m^2	25.1 ± 4.1	25.4 ± 3.9	23.7 ± 5.1
Isolated PCL tear	10	7	3
Combined injury	22	16	6
PCL reconstruction graft tears			
Patients	11	8	3
Age, y	35.5 ± 14.4	34.8 ± 15.1	37. 3 ± 15.3
BMI, kg/m^2	25.8 ± 3.7	27.2 ± 3.2	22.1 ± 2.2
Isolated PCL tear	3	2	1
Combined injury	8	6	2
Ligament intact controls			
Participants	100	50	50
Age, y	49.1 ± 16.6	47.8 ± 15.4	51.2 ± 15.0
BMI, kg/m^2	25.6 ± 4.2	27.1 ± 3.1	25.5 ± 4.0

[a]Values are presented as No. or mean ± SD. BMI, body mass index; PCL, posterior cruciate ligament.

34 patients (Table 2). Of 11 patients with PCL graft tears, 10 (90.9%) described a new injury since their primary PCL reconstruction. It is unclear whether the patient-reported new injuries caused the failure of the primary PCL reconstructions or if it was due to other extraneous variables (ie, graft selection, surgical technique, early return to activity). However, the mean time from recognition of the recurrent instability or reinjury of the graft to revision PCL reconstruction was 32.5 ± 8.0 weeks. Of note, all patients with a PCL graft tear had a primary PCL reconstruction with a single-bundle PCL graft that ultimately failed (Table 3).

TABLE 2
Concomitant Injuries, Including Grade 3 Ligamentous Tears, Treated at the Time of PCL Reconstruction[a]

Concomitant Injury/Treatment	No. of Injuries	Percentage of Patients
Meniscal tear	55	55
Medial	30	30
Lateral	23	23
Meniscectomy	24	44
Repair	23	42
FCL tear/reconstruction	7	7
MCL tear/reconstruction	34	34
PLC injury/reconstruction	24	24
Genu varum / proximal tibial osteotomy	9	9

[a]FCL, fibular collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament; PLC, posterolateral corner.

Radiologist Interpretation of MRI

Seventy-eight patients (87.6%) with primary PCL tears were accurately diagnosed on MRI by the interpreting musculoskeletal radiologist. Of the 78 patients, MRI sensitivity was 100% and 62.5% for acute and chronic tears, respectively. Only 2 (18.1%) patients who underwent a revision PCL reconstruction were accurately diagnosed on MRI preoperatively by the interpreting musculoskeletal radiologist.

PTT on MRI

In the chronic PCL cohort, mean PTT in the medial compartment was 3.8 mm, which was significantly greater than the mean PTT in the medial compartment of the control group (–2.3 mm, $P < .001$; negative denotes anterior translation). In the revision PCL cohort, a significant increase of 5.7 mm of posteromedial tibial translation was found when compared with that of uninjured controls ($P < .001$). A significant difference in medial compartment PTT was also found when the acute PCL group was compared with the chronic and revision PCL groups ($P = .025$, $P = .007$, respectively). Mean PTT measurements for acute, chronic, and revision groups on MRI are reported in Table 4.

ROC Curves

Chronic PCL. The mean value for medial compartment PTT in the chronic PCL group was 3.8 mm. An ROC curve was then built to identify the diagnostic utility of

TABLE 3
Previous Graft Type, Number of Revisions, and Time From Primary to Revision PCL Reconstruction and From Patient-Reported Reinjury to Revision PCL Reconstruction (n = 11)[a]

No.[b]	Primary PCL Reconstruction Graft Type	No. of Previous Revisions	Time From Primary to Revision, wk[c]	Time From Reinjury to Revision, wk
7	SB Achilles allo	1	104	N/A
12	SB Achilles allo	1	260	28
20	SB Achilles allo	1	156	52
44	SB hamstring allo	1	52	12
50	SB hamstring allo	1	364	104
69	SB quadriceps auto	1	60	10
75	SB Achilles allo	1	166.4	24
96	SB Achilles allo	1	520	4
98	SB hamstring auto and SB hamstring auto (contralateral)	2	124.8	8
99	SB hamstring allo and DB Achilles and hamstring allo	2	312	8
100	SB Achilles allo	1	93.6	4

[a]allo, allograft; auto, autograft; DB, double bundle; N/A, not applicable; PCL, posterior cruciate ligament; SB, single bundle.
[b]De-identified study number for patients with revision PCL reconstruction.
[c]Mean time from primary to revision PCL reconstruction was 3.8 ± 2.8 years.

TABLE 4
Mean Posterior Tibial Translation for Patients With Acute Primary, Chronic Primary, and Postreconstruction Graft PCL Injuries[a]

	Mean Tibial Translation, mm	
Cohort	Medial	PM-PL
Controls (n = 100)	–2.3	3.0
Acute (n = 57)	1	3.0
Chronic (n = 32)	3.8	3.5
Graft (n = 11)	3.4	4.0
P value		
Acute vs chronic	.025	.001
Acute vs graft	.007	.269

[a]There were no significant differences between acute and chronic tibial translation or acute and revision tibial translation ($P > .05$). A negative amount of translation reflects anterior subluxation of the tibia relative to the femur. PCL, posterior cruciate ligament; PM-PL, measurement difference of posterior medial vs posterior lateral tibial translation.

measuring medial compartment PTT for the detection of chronic PCL injuries. The AUROC was 0.834 ($P < .001$), and the ROC curve indicated that the most accurate cutoff point for the detection of chronic PCL tears was 2.0 mm of medial compartment PTT (sensitivity, 0.80; specificity, 0.89) (Figure 3).

Revision PCL Reconstruction. The mean value for medial compartment PTT in the revision group was 3.4 mm. A ROC curve was built to identify the diagnostic utility of medial compartment PTT measurement for patients with suspected PCL graft failure. The AUROC was 0.845 ($P < .001$), and the ROC curve that indicated the most accurate medial compartment PTT cutoff point for the detection of PCL graft failure was 3.6 mm (sensitivity, 0.92; specificity, 0.5) (Figure 4).

DISCUSSION

The main finding of this study was that PTT measurements of the medial compartment on MRI improved diagnostic sensitivity as compared with a radiologist's interpretation of a chronic PCL tear or PCL graft tear on MRI. In chronic cases, 2.0 mm of posteromedial tibial translation had a sensitivity of 80% and a specificity of 89%, compared with 62.5% sensitivity as found on radiologist interpretation of the MRI. Furthermore, in revision cases, 3.6 mm of PTT in the medial compartment had a sensitivity of 92% and a specificity of 72%, compared with 18.1% sensitivity as found on radiologist interpretation of the MRI.

It has been reported that >50% of PCL tears are seen by clinicians >1 year after injury,[19] highlighting the need to manage chronic PCL tears appropriately to improve prognosis. MRI has been reported to have a high diagnostic accuracy for acute PCL tears; however, the sensitivity in chronic cases has been reported to be low.[5] A biomechanical study performed by Kennedy et al[14] demonstrated that a complete tear of the PCL causes excessive increases in posterior translation and internal rotation of the tibia. The coupled PTT and internal rotation can explain the posterior translation of the medial tibial plateau that can be seen on MRI in complete PCL tears.[15,27]

Although the PCL has been reported to have good intrinsic healing potential, when treated nonoperatively, the ligament tends to heal in an elongated and attenuated condition.[20,25] On MRI examination, up to 75% of PCL tears retain continuity,[2,17] which suggests that the PCL is nondisrupted or an injury has healed.[25] According to Akisue et al,[2] the average time from the original injury to MRI was 17 months (minimum of 12 months) with a continuous PCL noted in 75% of cases. According to Rodriguez et al,[17] the average time from original injury to MRI was 54.8 days (range, 1-529 days), with a continuous PCL noted in 62% of cases. Given this diagnostic challenge, secondary

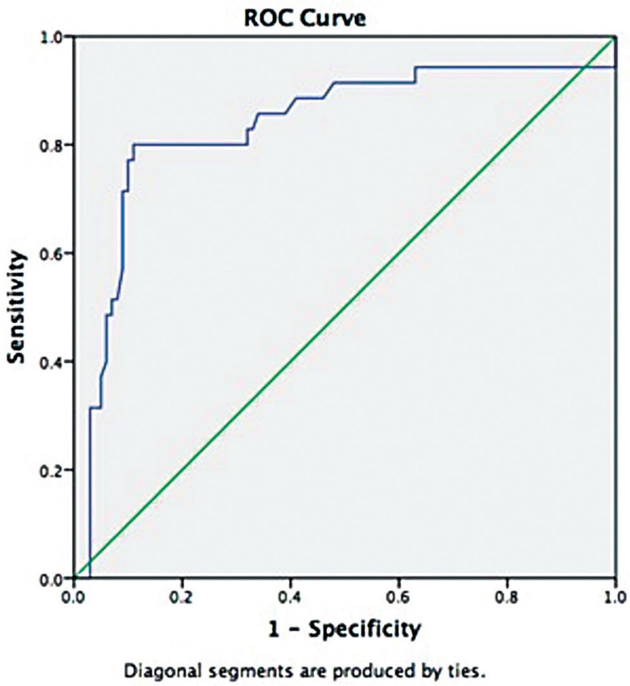

Figure 3. Receiver operating characteristic curve for difference of medial compartment posterior tibial translation among patients with chronic posterior cruciate ligament tears (n = 32).

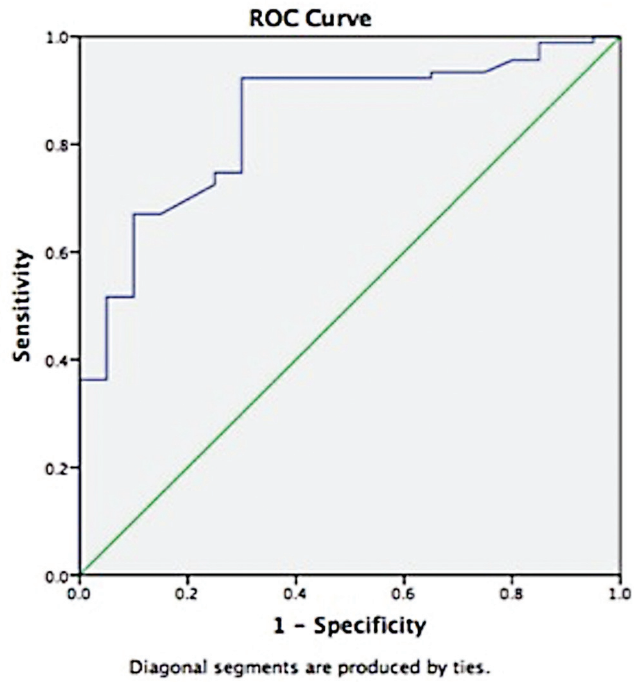

Figure 4. Receiver operating characteristic curve for posteromedial tibial translation among patients with revision posterior cruciate ligament reconstruction (n = 11).

signs, such as PTT on routine MRI, play an important role in the diagnosis and management of PCL injuries. Subsequently, these findings may lead the clinician toward further testing, including stress radiographs, which have been reported to provide a more objective method to assess the structural integrity of the PCL.[10,12,16,18] The ability to use PTT measurements on MRI may help identify patients with chronic PCL tears that have healed in an elongated condition or that warrant surgical reconstruction, potentially decreasing the risk of degenerative changes associated with chronic PCL injuries and improving patient-reported outcomes.

In the present study, 100% of acute primary PCL tears were diagnosed on radiologist interpretation of the MRI, compared with 62.5% of chronic PCL tears. Furthermore, only 2 (18.1%) of the patients who had revision PCL surgery were diagnosed preoperatively by a musculoskeletal radiologist. Utilizing a previously described measurement technique,[4,26] we found that an increase in posteromedial tibial translation of 2.0 mm for chronic tears and 3.6 mm for PCL graft failures resulted in sensitivities of 80% and 92% for chronic PCL tears and PCL graft tears, respectively. This technique dramatically improved the diagnostic sensitivity by 17.5% for chronic PCL injuries and 74% for PCL graft when compared with the diagnostic sensitivity of the interpreting musculoskeletal radiologist.

Degnan et al[4] described posteromedial tibial translation on MRI as a secondary finding of isolated PCL rupture in 11 cases; 3 of which were acute, 1 subacute, and 7 chronic at the time of MRI. A significant increase of 2.93 mm of posteromedial tibial translation versus uninjured controls was reported. The same authors found the PTT measurement technique to be highly reliable, with intraclass correlations ranging from 0.94 to 0.96; however, diagnostic sensitivity was not reported.[4] In the present study, a significantly greater amount of increased posteromedial tibial translation was found on MRI for PCL graft tears (3.4 mm) as compared with PCL-intact controls (–2.3 mm). The PTT measurement technique also resulted in high reliability with our raters, with intraclass correlations of 0.85 and 0.90 for the chronic and revision cohorts, respectively. Therefore, posteromedial tibial translation measured on MRI may serve as a valuable and reliable tool to assess functionality of the PCL in the setting of chronic primary and postreconstruction graft injuries with an intact ACL—especially when there is continuity of the PCL/graft on MRI.

We acknowledge some limitations to our study. The injury patterns in this cohort included isolated and combined PCL injuries, which potentially affected the amount of PTT on MRI. The qualities of the MRI were variable, including 1.5-Tesla and 3.0-Tesla, but all patients included in this study had MRI that could be evaluated reliably. Also, there was variability in the imaging center and interpreting radiologist; however, this variability may improve the generalizability of these findings because it replicates the clinical scenario. The fact that an experienced surgeon in a tertiary referral center performed all the surgical procedures may also limit the external validity of the results, although it does provide reliability in the intraoperative evaluation of PCL integrity.

CONCLUSION

MRI evaluation of the PCL fibers had poor sensitivity for chronic PCL tears and PCL reconstruction graft tears. The sensitivity for diagnosing chronic PCL tears and PCL reconstruction graft failures was improved by measuring posteromedial tibial translation.

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