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Decreased Posterior Tibial Slope Does Not Impact Postoperative Posterior Knee Laxity after Double-Bundle Posterior Cruciate Ligament Reconstruction

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Abstract

Background: Recent clinical studies have identified sagittal plane posterior tibial slope as a risk factor for increased postoperative laxity after single-bundle (SB) posterior cruciate ligament reconstruction (PCLR). However, the effect of tibial slope and its role in graft laxity following double-bundle (DB) PCLR has not been investigated clinically. .

Purpose/Hypothesis: The purpose of this study was to retrospectively compare the degree of posterior tibial slope and its impact on posterior tibial translation (PTT) after DB PCLR. It was hypothesized that preoperative tibial slope would not be associated with graft laxity following DB PCLR.

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

Methods: Patients who underwent primary DB PCLR without ACL injury between 2010 and 2017 by a single surgeon were retrospectively analyzed. Measurements of posterior tibial slope were performed using the lateral radiograph and PTT was measured using kneeling PCL stress radiographs, preoperatively and at a minimum of 1-year postoperatively. Linear regression was used to assess the relationship between native posterior tibial slope and postoperative graft laxity, determined by PCL stress radiographs.

Results: One hundred three patients with PCL tears and subsequent reconstructions were included. The mean posterior tibial slope for all patients was 5.9° $\pm$ 2.2° (95% confidence interval [CI]: 5.3˚, 6.1˚). There was a significant reduction of the mean side-to-side difference (SSD) in PTT between preoperative (10.6 $\pm$ 2.7 mm) and postoperative (1.5 $\pm$ 2.6 mm) PCL stress radiographs following DB PCLR (mean difference = 9.1 mm; 95% CI [8.4, 9.], $p < 0.001$). Combined ligament injury (beta = -1.01, 95% CI [-2.00, -0.01], $p = 0.047$) was a significant independent predictor of decreased postoperative SSD in PTT on PCL stress radiographs. Four (4%) patients demonstrated failed PCLRs, as defined by PTT ≥ 8 mm on PCL stress radiographs.

Conclusion: Graft laxity, determined by PTT in posterior kneeling stress radiographs, was not influenced by decreased posterior tibial slope in patients following DB PCLRs. With further blinded-comparison studies required to corroborate these findings, the current recommendation for DB PCLR is reinforced by the lack of a decreased degree of tibial slope's impact on graft laxity compared to its negative effect on SB PCLRs.

Keywords: posterior cruciate ligament; tibial slope; posterior tibial translation; kneeling stress radiographs; posterior knee instability

INTRODUCTION

Persistent posterior knee laxity following posterior cruciate ligament (PCL) reconstruction has been a recurrent problem faced by clinicians when treating PCL tears. It has been described that tunnel placement, fixation angles, graft choice, and single- or double-bundle techniques have important roles in restoring the native kinematics of the knee joint after injury.[4, 5, 11, 13] However, with efforts to improve surgical procedures for PCL reconstruction (PCLR), there still remains suboptimal postoperative subjective and objective outcomes reported in the literature.[15, 20] Previous studies have suggested that the bony anatomy of the tibial plateau, most notably sagittal tibial slope, may play an underlying role in patient subjective outcomes and residual PCL graft laxity following PCLR.[2, 6, 8]

Sagittal plane tibial slope has previously been described as averaging 7-10° posteriorly and is suggested to have a significant impact on *in situ* forces on the cruciate ligaments.[7, 16, 19] In particular, in single-bundle (SB) PCL reconstructed knees, a decreased posterior tibial slope has been reported to correlate with significantly higher residual posterior tibial translation (PTT), indicative of persistent PCL graft laxity, postoperatively.[8, 11, 18]

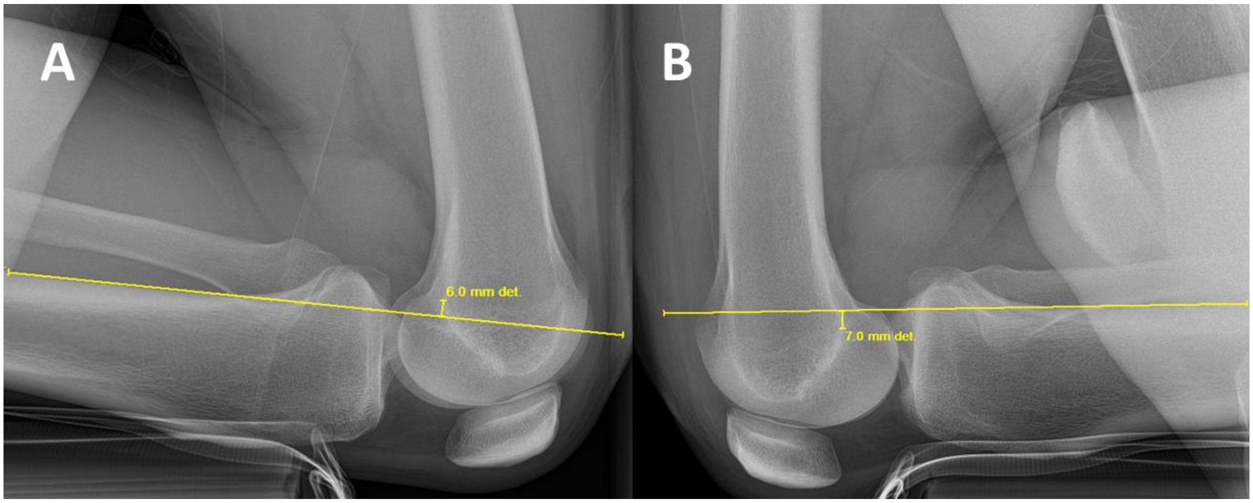
Double-bundle (DB) PCLRs have been recently reported to biomechanically and clinically to perform well without significant laxity at follow-up.[12, 14, 21] However, the effects of sagittal plane tibial slope have yet to be investigated to evaluate its role in residual graft laxity after DB PCLR. The purpose of this study was to retrospectively compare the amount of posterior tibial slope and its impact on PTT after DB PCLR. It was hypothesized that preoperative tibial slope would not be associated with graft laxity following DB PCLR.

METHODS

Study Design

Following Institutional Review Board approval (*institution blinded for review*), patients who underwent primary PCLR between 2010 and 2017 by a single surgeon (*initials blinded for review*) were retrospectively analyzed. Preoperative posterior kneeling stress radiographs were obtained on all patients and the indication for a PCLR was a side-to-side difference (SSD) in PTT of ≥ 8 mm (Figure 1).[10, 21] Most of these patients were included in a previous study on DB DCLR outcomes (*reference blinded for review*). Inclusion criteria were defined as patients with an isolated PCL tear using posterior stress radiographs, combined PCL/FCL (fibular collateral ligament) tears using posterior and varus stress radiographs, PCL/MCL (medial collateral ligament) tears using posterior and valgus stress radiographs, or combined PCL/posterolateral corner injury using posterior and varus stress radiographs—confirmed at the time of exam under anesthesia (EUA). Exclusion criteria was defined by patients with a previously failed PCLR, patients with concomitant ACL and PCL injuries, and patients who had undergone a prior proximal tibial osteotomy. All patients were clinically examined preoperatively and underwent standardized preoperative imaging evaluation with plain and posterior knee stress radiographs and magnetic resonance imaging (MRI). Posterior kneeling stress radiographs were obtained on all patients preoperatively and at a minimum of 1-year postoperatively.

Figure 1. Posterior kneeling (PCL) stress radiographs. A) Lateral radiograph of uninjured left knee reveals 6.0 mm of anterior tibial translation compared to B) lateral radiograph of injured right knee with 7.0 mm of posterior tibial translation, indicating a complete PCL tear with a side-to-side difference of 13.0 mm of posterior tibial translation.

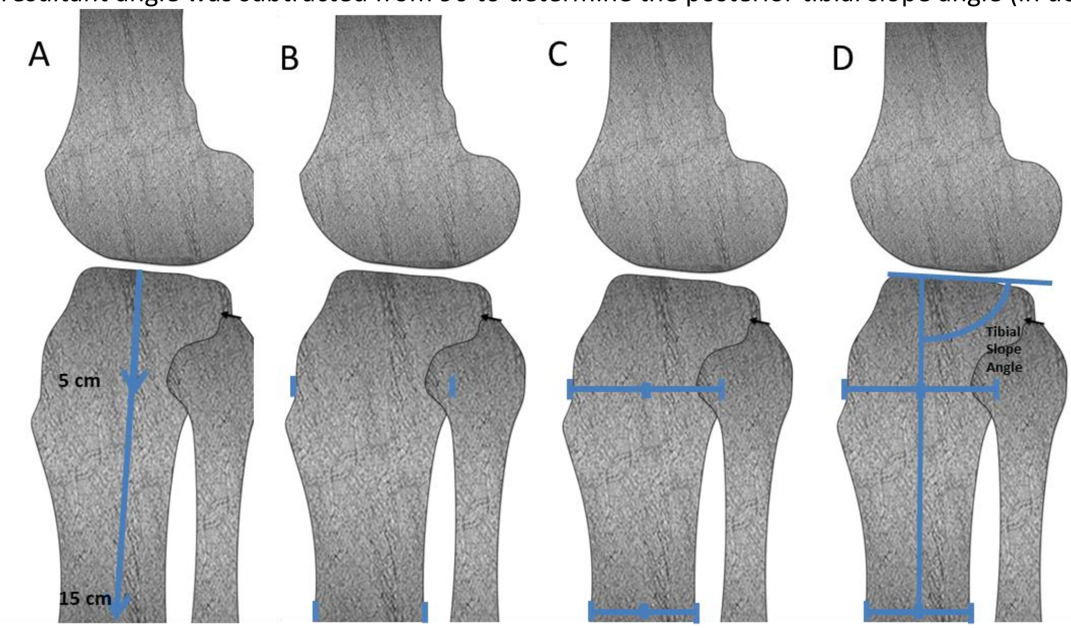


Imaging Evaluation

Posterior kneeling stress radiographs, clinical examination, EUA, and arthroscopic procedures were reviewed to determine the presence of a PCL tear and concomitant pathologies. Two independent raters (*initials blinded for review*) evaluated the preoperative lateral radiographs of the all PCL injured patients to measure the amount of posterior tibial slope according to a previously validated technique.[22]

Posterior tibial slope was measured by first marking the midpoints of the tibial diaphysis 5 and 15 cm distal to the joint line. A line was drawn to connect the two midpoints and the tibial proximal anatomical axis was drawn to intersect through both midpoints. The degree of posterior tibial slope was then measured as the angle derived from the posterior inclination of the medial and lateral tibial plateaus, and the perpendicular line drawn with respect to the tibial proximal anatomical axis. The slopes of the medial and lateral tibial plateaus were averaged to produce the final calculated posterior tibial slope value (Figure 2).[22] Stress radiographs were measured by the standard posterior knee kneeling technique as previously described both preoperatively and postoperatively and recorded as a SSD between injured and uninjured limbs (Figure 1).[10]

Figure 2. Schematic illustration demonstrating the described measurement technique for calculating sagittal plane tibial slope. A) First, the tibial joint line was located and lines perpendicular to the tibial shaft were drawn 5 and 15 cm distal. B) Next, anterior and posterior tibial cortices were marked at these points and C) a line was drawn at these two points and the mid-point of each line was marked. D) Using an angle tool (or Cobb tool) on an imaging software system, a vertical line was drawn connecting the center points of each line and a second horizontal line was drawn parallel to the joint surface. The resultant angle was subtracted from 90 to determine the posterior tibial slope angle (in degrees).



Statistical Analysis

To address the primary question of this study, ordinary least squares regression was used to test the association between preoperative tibial slope and postoperative SSD in PTT. Both simple and multiple linear regression was performed to estimate the unadjusted and adjusted effect of tibial slope, respectively. In the multiple linear regression model, combined ligamentous injury, injury chronicity, mechanism of injury, follow-up time, BMI and age at surgery were entered as possible confounders. The rule of thumb of one model parameter for every 15 patients was used to prevent model overfitting.[9] Residual diagnostics were performed to assess whether model assumptions were satisfactorily met. Additionally, a paired t-test was used to compare preoperative to postoperative SSD in PTT values. All graphs and analyses were completed with the statistical package R, version 3.5.0 (R Development Core Team, Vienna, Austria).[1]

RESULTS

Patient demographics for all patients are presented in Table 1. One-hundred and three patients with PCL tears were included. Each patient with a PCL tear underwent an arthroscopic DB PCLR technique.[3] Ninety (87.4%) patients reported a contact mechanism (i.e. fall onto a flexed knee) at the time of injury, while 13 (12.6%) patients reported a noncontact injury mechanism. Sixty-four (62.1%) patients had combined extra-articular ligament injuries that were concurrently reconstructed with the PCL tear, while isolated PCL tears were identified in 39 (37.9%) patients. Forty-nine (47.6%) patients had an acute (≤ 6 weeks) injury and 54 (52.4%) patients had a chronic (> 6 weeks) injury at the time of imaging and evaluation. Four (4%) patients demonstrated failed PCLRs, as defined by SSD in PTT ≥ 8 mm on PCL stress radiographs, and there were no reported complications during the postoperative period (Table 2).

The mean posterior tibial slope for all PCL injured patients was 5.9° $\pm$ 2.2°. There was a significant reduction in the amount of mean SSD in PTT between preoperative (10.6 $\pm$ 2.7 mm) and postoperative (1.5 $\pm$ 2.6) PCL stress radiographs following DB PCLR (mean difference = 9.1 mm; 95% CI [8.4, 9.8], $p < 0.001$) (Figure 3). Linear regression analysis revealed no significant correlation between preoperative posterior tibial slope and the amount of SSD in PTT on postoperative stress radiographs obtained at a mean 18.5 months postoperatively (R = -0.115, p

= 0.249) (Figures 4 & 5). Similarly, when adjusting for combined ligamentous injury, injury chronicity, mechanism of injury, BMI, and age at surgery via multiple linear regression, preoperative tibial slope was not a significant independent predictor of postoperative SSD in PTT (beta = -0.079, 95% CI [-0.308, 0.150], p = 0.496) (Table 3). Combined injury (beta = -1.01, 95% CI [-2.00, -0.01], p = 0.047) was a significant independent predictor of decreased postoperative SSD in PTT on posterior stress radiographs.

Clinical Characteristics	Total	Male	Female
Gender	n = 103	n = 80 (78%)	n = 23 (22%)
Age (years)*	31.5 ± 12.6	30.6 ± 12.6	34.7 ± 12.5
BMI (kg/m^2)*	24.6 ± 3.6	24.3 ± 2.7	25.5 ± 5.6
Isolated PCL Tear	n = 39	n = 28	n = 11
Combined Injury	n = 64	n = 52	n = 12
Acute PCL Injury (< 6 weeks)	n = 49	n = 42	n = 7
Chronic PCL Injury (> 6 weeks)	n = 54	n = 38	n = 16

Table 1. Demographics and clinical characteristics of the PCL injured patients. BMI: body mass index. *Mean ± standard deviation.

Patient No.	Concomitant Surgical Procedures	Time from Surgery to PCLR Graft Laxity	Re-Injury Reported?	Preoperative Stress SSD*	Postoperative Stress SSD*
1	MCLR	4 years	No	20 mm	8 mm
2	MCLR, lateral meniscus repair, ORIF tibial plateau fracture	1 year	Yes: weighted deep squats	8 mm	8 mm
3	PLCR	6 years	No	12 mm	17 mm
4	Isolated PCLR	5 years	Yes: fall onto flexed knee	8 mm	8 mm

Table 2. Clinical characteristics of patients with failed double-bundle PCL reconstructions (PCLR). *Failure was defined by posterior keeling stress radiographs with a side-to-side difference (SSD) of ≥ 8 mm at a minimum of 1-year postoperatively. MCLR: medial collateral ligament reconstruction; ORIF: open reduction internal fixation; PLCR: posterolateral corner reconstruction.

Figure 3. Postoperative kneeling stress radiographs demonstrating restoration of posterior knee stability at 2-years follow-up in a patient following DB PCLR. A) Uninjured left knee

demonstrating posterior tibial translation of 8.8 mm. B) Injured right knee demonstrating 8.7 mm of posterior tibial translation, indicating a side-to-side difference of 0.1 mm following DB PCLR at 2-years follow-up. DB PCLR: double-bundle posterior cruciate ligament reconstruction.

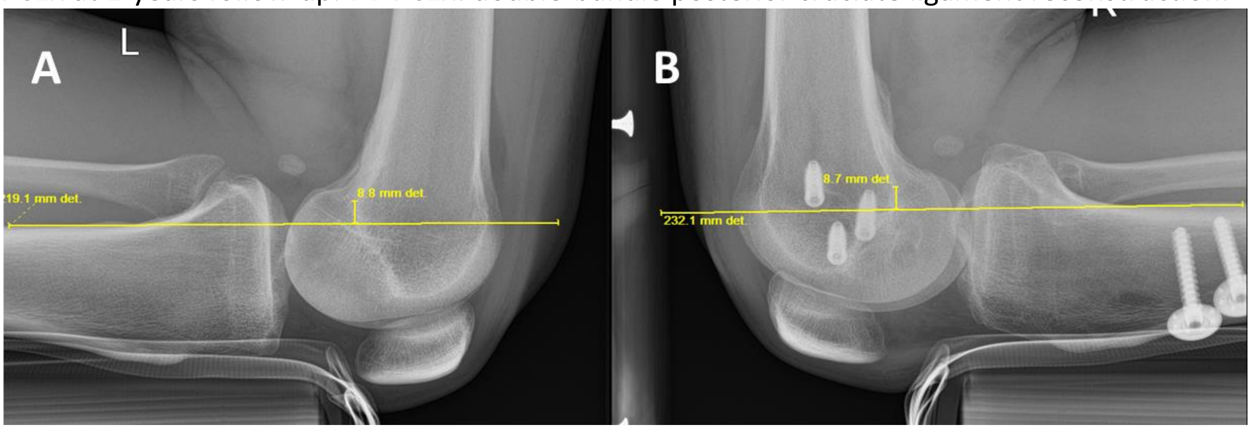


Figure 4. Scatterplot with unadjusted linear regression relationship between preoperative posterior tibial slope and postoperative residual posterior tibial translation (PTT). Gray shaded area represents 95% confidence region for the regression line. There was no significant correlation between the preoperative posterior tibial slope (x-axis) and postoperative posterior tibial translation (y-axis) (R = -0.115, p = 0.249).

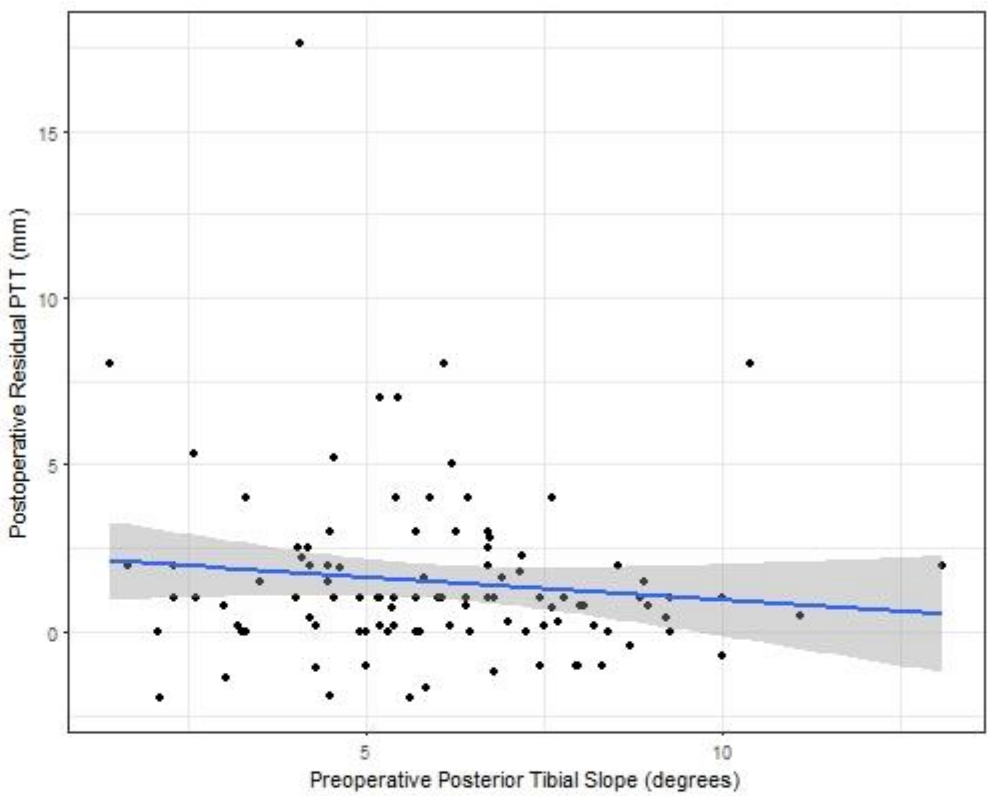
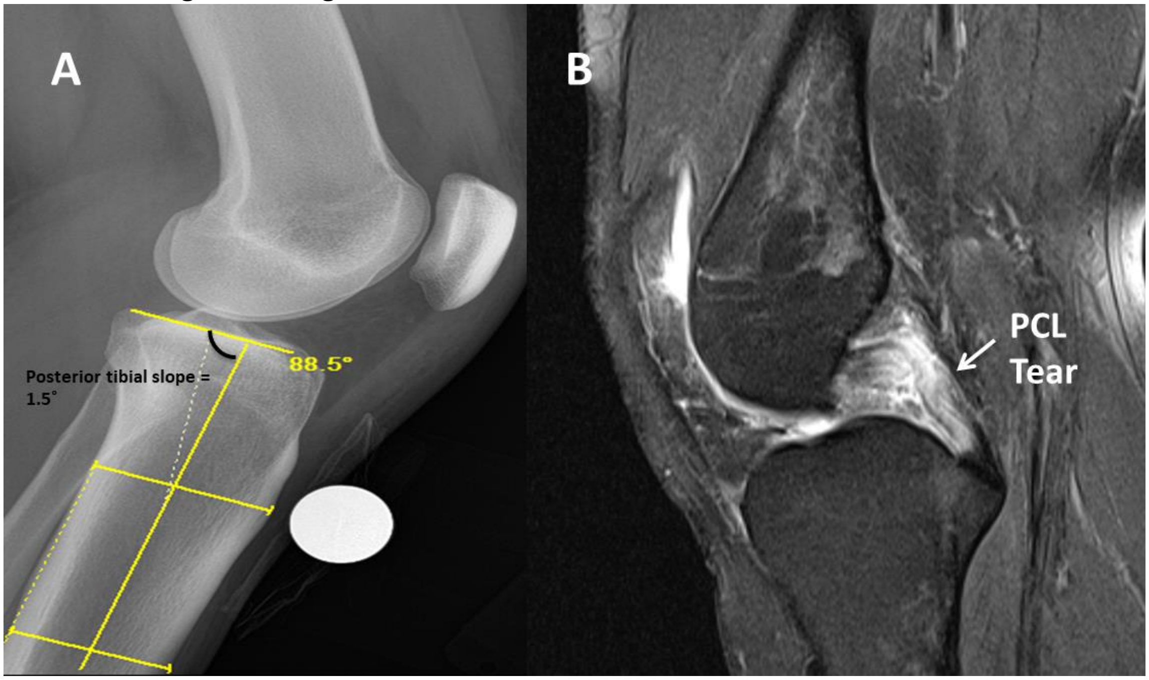


Figure 5. A) Tibial slope measurement of a patient with a PCL tear reveals a decreased posterior tibial slope measuring 1.5°. B) T2-weighted sagittal view on magnetic resonance imaging (MRI) demonstrating an acute grade III PCL tear.



	Beta	95% CI	Std. Error	t-value	p-value
(Intercept)	1.303	[-3.173, 5.778]	2.25	0.58	0.565
Tibial Slope	-0.079	[-0.308, 0.15]	0.12	-0.68	0.496
Combined Injury	-1.01	[-2, -0.01]	0.5	-2.01	0.047
Chronic Injury (> 6 weeks)	-0.69	[-1.65, 0.27]	0.48	-1.42	0.158
Contact Mechanism of Injury	0.76	[-0.75, 2.27]	0.76	1	0.322
Follow-up time (months)	0.062	[0.03, 0.094]	0.02	3.81	<0.001
Body Mass Index	-0.056	[-0.192, 0.081]	0.07	-0.81	0.421
Age at Surgery	0.031	[-0.008, 0.07]	0.02	1.59	0.115

Table 3. Multiple linear regression model for postoperative residual PTT. Preoperative tibial slope was not a significant independent predictor (p = 0.496). Beta values are the expected change in PTT given a one unit increase in that covariate, holding all other variables constant. PTT: posterior tibial translation.

DISCUSSION

The main finding of this study was that we confirmed our hypothesis that posterior tibial slope had no correlation with the amount of DB PCLR graft laxity as measured by posterior kneeling stress radiographs. Combined PCL injury was a significant independent predictor of decreased postoperative SSD in PTT on posterior stress radiographs. Additionally, the majority of patients (96%) demonstrated improved objective posterior knee stability following DB PCLR. Thus, DB PCLR can be recommended as a surgical treatment option for patients with grade III isolated and combined PCL injuries, irrespective of native posterior tibial slope.

In the current study, the mean slope for PCL injured patients was 5.9° which is lower than previous reports of 8.0° for PCL injured patients.[8] Previous studies investigating the influence of sagittal tibial slope on knee kinematics, native ligament force, and PCLR graft laxity have been reported.[2, 6, 8, 17, 19] The majority of studies have suggested that increasing native posterior tibial slope by an anterior opening wedge osteotomy may supplement soft-tissue reconstruction and improve knee stability and protect native and reconstructed PCLs.[2, 6, 7, 17] Only one previous clinical study has investigated the correlation of posterior tibial slope and SB PCLR graft laxity and reported that decreased tibial slope was significantly correlated with increased PTT on kneeling stress radiographs.[8] In contrast, the current study showed that a flattened preoperative tibial slope had no effect on postoperative PTT following DB PCLR.

The findings of this study suggests that PCL stability can be achieved in patients following DB PCLR despite having a less than average preoperative amount of posterior tibial slope (< 6°). In addition, we found that combined PCLR (with other concurrent knee ligament reconstructions) had less laxity than isolated DB PCLR. We theorize that this may be due to the fact that a combined injury patients required more additional surgery to stabilize their knee and this may contribute to more inflammation after surgery and potentially a more stable knee.

Therefore, it is suggested that further studies evaluate the effects of posterior tibial slope and DB PCLR graft laxity for isolated and combined injuries and with long-term follow-up.

We acknowledge some limitations to our study. Although graders were blinded to patient information, there was potential for observer bias due to the awareness of the study hypothesis by the research team performing the radiographic measurements. Since the patient cohort was taken from one surgeon's records, our study was unable to provide a comparison with SB PCLRs. As a result, we are unable to draw direct conclusions of PCL graft laxity in DB PCLR relative to SB PCLR.

Conclusion

Graft laxity, determined by PTT in posterior kneeling stress radiographs, was not influenced by decreased posterior tibial slope in patients following DB PCLRs. With further blinded-comparison studies required to corroborate these findings, the current recommendation for DB PCLR is reinforced by the lack of tibial slope's impact on graft laxity compared to its negative effect on SB PCLR.

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