Decreased Posterior Tibial Slope Does Not Affect Postoperative Posterior Knee Laxity After Double-Bundle Posterior Cruciate Ligament Reconstruction

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Background: Recent clinical studies identified sagittal plane posterior tibial slope as a risk factor for increased postoperative laxity after single-bundle posterior cruciate ligament reconstruction (PCLR).

Purpose/Hypothesis: To retrospectively compare the degree of posterior tibial slope and its effect on posterior tibial translation (PTT) after double-bundle (DB) PCLR. Our null hypothesis was that preoperative tibial slope would not be associated with graft laxity.

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

Methods: Patients who underwent DB PCLR between 2010 and 2017 by a single surgeon were retrospectively analyzed. Measurements of posterior tibial slope were performed on lateral radiographs, and PTT was measured with pre- and postoperative kneeling stress radiographs. Simple and multiple linear regression was performed to estimate the unadjusted and adjusted effect of tibial slope on postoperative graft laxity, respectively.

Results: A total of 103 patients with posterior cruciate ligament tears and subsequent reconstructions were included. There was a significant reduction of the mean $\pm$ SD side-to-side difference in PTT between stress radiographs (preoperative, 10.6 $\pm$ 2.7 mm; postoperative, 1.5 $\pm$ 2.6 mm; mean difference, 9.1 mm; 95% CI, 8.4-9.8; $P < .001$). Linear regression analysis revealed no significant correlation between preoperative posterior tibial slope and the amount of side-to-side difference in PTT on postoperative stress radiographs obtained at a mean 18.5 months ($R = -0.115$, $P = .249$). Combined ligament injury (beta = -1.01; 95% CI, -2.00 to -0.01; $P = .047$) was a significant independent predictor of decreased postoperative side-to-side difference in PTT.

Conclusion: Graft laxity, determined by PTT in posterior kneeling stress radiographs, was not influenced by decreased posterior tibial slope after DB PCLRs. The observed results in the current study support the use of DB PCLR. Future studies should be conducted to compare the effect of tibial slope after SB PCLR and DB PCLR at long-term follow-up.

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

Persistent posterior knee laxity after posterior cruciate ligament reconstruction (PCLR) has been a recurrent problem faced by clinicians when treating posterior cruciate ligament (PCL) tears. It has been described that tunnel placement, fixation angles, graft choice, and single-bundle (SB) or double-bundle (DB) 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 PCLR, there still remains suboptimal postoperative subjective and objective outcomes reported in the literature.[15,20] Previous studies suggested that the bony anatomy of the tibial plateau—most notably, the sagittal tibial slope—may play an underlying role in subjective outcomes and residual PCL graft laxity after PCLR.[1,6,8]

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

DB PCLRs were recently reported to biomechanically and clinically 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

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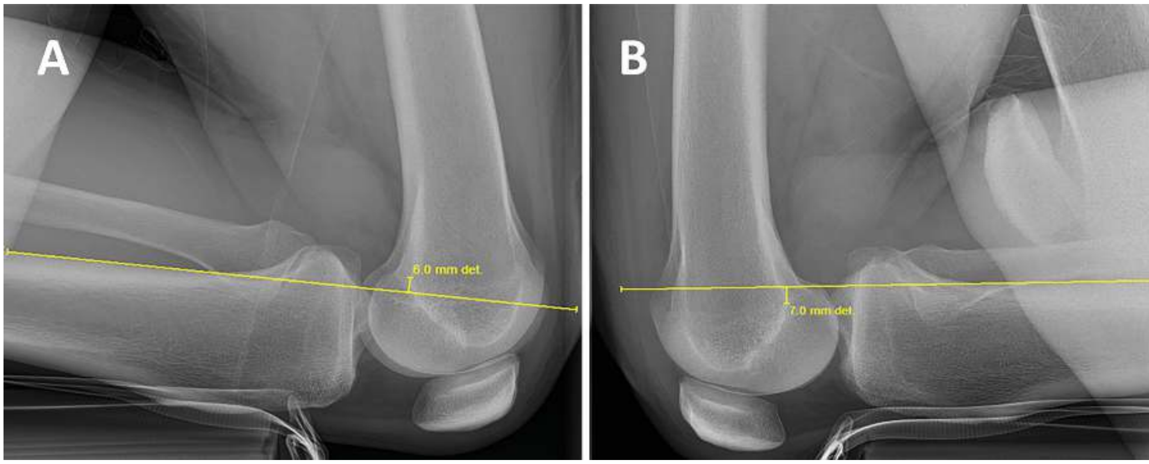

Figure 1. Posterior kneeling (PCL) stress radiographs. (A) A lateral radiograph of an uninjured left knee reveals 6.0 mm of anterior tibial translation, as compared with (B) a lateral radiograph of an injured right knee with 7.0 mm of posterior tibial translation, indicating a complete PCL tear with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

graft laxity after DB PCLR. The purpose of this study was to retrospectively compare the amount of posterior tibial slope and its effect on PTT after DB PCLR. Our null hypothesis was that preoperative tibial slope would not be associated with graft laxity after DB PCLR.

METHODS

Study Design

Following institutional review board approval (Vail Health Hospital), patients who underwent primary PCLR between 2010 and 2017 by a single surgeon (R.F.L.) 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 $\geq$8 mm (Figure 1).[10,21] Most of these patients were included in a previous study on DB PCLR outcomes.[2] Inclusion criteria were defined as follows: 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 were defined as a previously failed PCLR, concomitant anterior cruciate ligament and PCL injuries, and 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. Posterior kneeling stress radiographs were obtained on all patients preoperatively and at a minimum of 6 months postoperatively.

Imaging Evaluation

Posterior kneeling stress radiographs, clinical examination, examination under anesthesia, and arthroscopic procedures were reviewed to determine the presence of a PCL tear and concomitant injuries. Two independent raters (A.S.B., N.N.D.) evaluated the preoperative lateral radiographs of the all PCL-injured knees 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 2 midpoints, and the tibial proximal anatomic 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 anatomic axis. The slopes of the medial and lateral tibial plateaus were averaged to produce the

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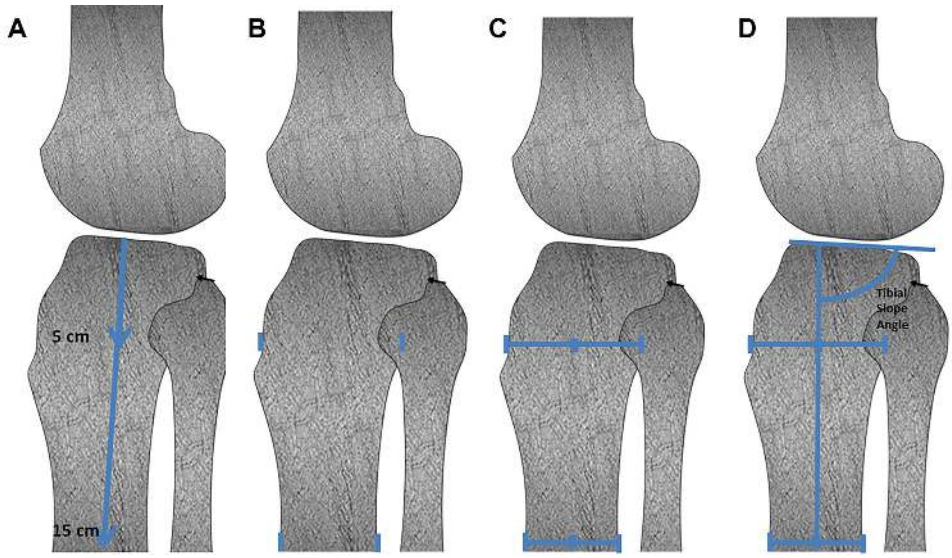

Figure 2. Schematic illustration demonstrating the described measurement technique for calculating sagittal plane tibial slope. (A) First, the tibial joint line was located and lines perpendicular to the tibial shaft were drawn 5 and 15 cm distal. (B) Next, anterior and posterior tibial cortices were marked at these points, and (C) a line was drawn at these 2 points and the midpoint of each line was marked. (D) With 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).

final calculated posterior tibial slope value (Figure 2).[22] Stress radiographs were measured pre- and postoperatively by the standard posterior kneeling technique, as previously described, and recorded as an SSD between injured and uninjured limbs (Figure 1).[10]

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. 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, body mass index, and age at surgery were entered as possible confounders. The general rule of 1 model parameter for every 15 patients was used to prevent model overfitting.[9] A sample size calculation was made to determine the required sample size necessary to detect a Pearson correlation magnitude of 0.3, which is conventionally considered a "medium" strength correlation. Based on the assumption of 2-tailed testing and an alpha level of .05, 82 patients were sufficient to detect an effect size of $|r| = 0.3$ with 80% statistical power. Residual diagnostics were performed to assess whether model assumptions were satisfactorily met. Additionally, a paired t test was used to compare pre- with postoperative SSD in PTT values. All graphs and analyses were completed with the statistical package R (v 3.5.0; R Development Core Team).

RESULTS

Demographics for all patients are presented in Table 1; 103 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 (ie, fall onto a flexed knee) at the time of injury, while 13 (12.6%) reported a noncontact 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%). Forty-nine (47.6%) patients had an acute injury ($\leq$6 weeks), and 54 (52.4%) had a chronic injury (>6 weeks) at the time of imaging, evaluation, and surgery. Four (4%) patients demonstrated failed PCLRs during the study, as defined by SSD in PTT $\geq$8 mm on PCL stress radiographs, and there were no reported complications during the postoperative period (Table 2).

Postoperative kneeling stress radiographs were obtained at a mean 18.5 months (range, 6-84 months). The mean ± SD posterior tibial slope for all PCL injured patients was 5.9° ± 2.2°. There was a significant reduction in the amount of mean SSD in PTT between PCL stress radiographs (preoperative, 10.6 ± 2.7 mm; postoperative, 1.5 ± 2.6) after DB PCLR (mean difference = 9.1 mm; 95% CI, 8.4-9.8; $P < .001$) (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 ($R = -0.115$, $P = .249$) (Figures 4 and 5). Similarly, with adjustment for combined ligamentous injury, injury chronicity, mechanism of injury, body mass index, and age at surgery via multiple linear regression,

TABLE 1
Demographics and Clinical Characteristics of the PCL-Injured Knees[a]

Clinical Characteristic	Total	Male	Female
Patients	103	80 (78)	23 (22)
Age, y	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	39	28	11
Combined injury	64	52	12
PCL–medial collateral ligament	36		
PCL–fibular collateral ligament	6		
PCL–posterolateral corner	22		
PCL injury			
Acute, ≤6 wk	49	42	7
Chronic, >6 wk	54	38	16

[a]Values are presented as n (%) or mean ± SD. BMI, body mass index; PCL, posterior cruciate ligament.

TABLE 2
Clinical Characteristics of Patients With Failed Double-Bundle PCLR[a]

No.	Concomitant Surgical Procedures	Time From Surgery to PCLR Graft Laxity, y	Reinjury Reported?	Stress SSD, mm[b]	
				Preoperative	Postoperative
1	MCLR	4	No	20	8
2	MCLR, lateral meniscus repair, ORIF tibial plateau fracture	1	Yes: weighted deep squats	8	8
3	PLCR	6	No	12	17
4	Isolated PCLR	5	Yes: fall onto flexed knee	8	8

[a]MCLR, medial collateral ligament reconstruction; ORIF, open reduction internal fixation; PCLR, posterior cruciate ligament reconstruction; PLCR, posterolateral corner reconstruction; SSD, side-to-side difference.
[b]Failure was defined by posterior kneeling stress radiographs with a SSD ≥8 mm at a minimum of 6 months postoperatively.

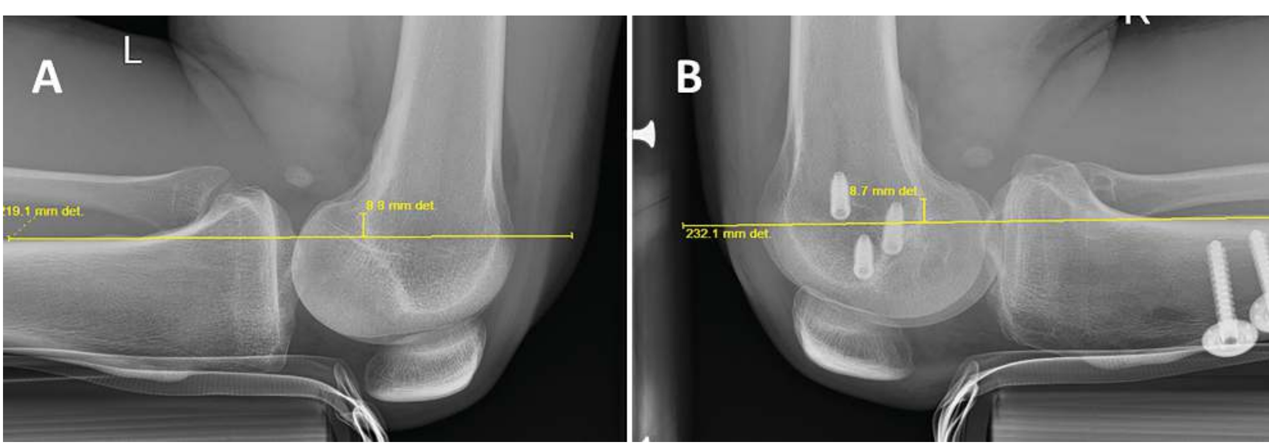

Figure 3. Postoperative kneeling stress radiographs showing restoration of posterior knee stability at 2-year follow-up after DB PCLR. (A) Uninjured left knee demonstrating posterior tibial translation of 8.8 mm. (B) Injured right knee displaying 8.7 mm of posterior tibial translation, indicating a side-to-side difference of 0.1 mm after DB PCLR at 2-year follow-up. DB PCLR, double-bundle posterior cruciate ligament reconstruction.

preoperative tibial slope was not a significant independent predictor of postoperative SSD in PTT (beta = −0.079; 95% CI, −0.308 to 0.150; *P* = .496) (Table 3). Combined injury (beta = −1.01; 95% CI, −2.00 to −0.01; *P* = .047) was a significant independent predictor of decreased postoperative SSD in PTT on posterior stress radiographs.

TABLE 3
Multiple Linear Regression Model for Postoperative Residual PTT[a]

	Beta	95% CI	SE	t Value	P Value
(Intercept)	1.303	–3.173 to 5.778	2.25	0.58	.565
Tibial slope	–0.079	–0.308 to 0.15	0.12	–0.68	.496
Combined injury	–1.01	–2 to −0.01	0.5	–2.01	.047
Chronic injury, >6 wk	–0.69	–1.65 to 0.27	0.48	–1.42	.158
Contact mechanism of injury	0.76	–0.75 to 2.27	0.76	1	.322
Follow-up time, mo	0.062	0.03 to 0.094	0.02	3.81	<.001
Body mass index	–0.056	–0.192 to 0.081	0.07	–0.81	.421
Age at surgery, y	0.031	–0.008 to 0.07	0.02	1.59	.115

[a]Preoperative tibial slope was not a significant independent predictor (P = .496). Beta values are the expected change in PTT given a 1-unit increase in that covariate, holding all other variables constant. PTT, posterior tibial translation.

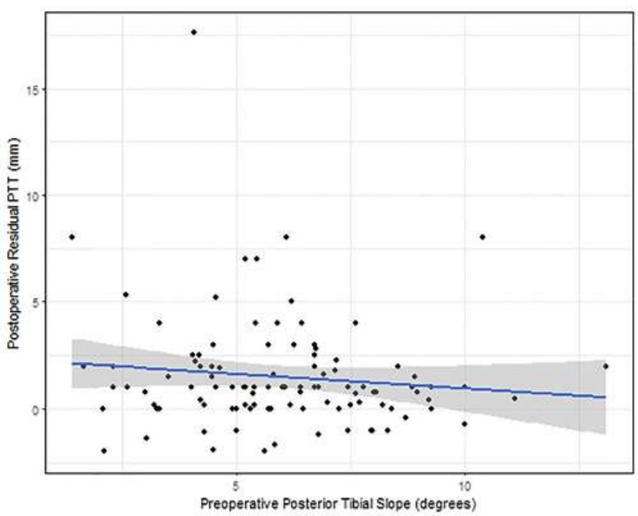

Figure 4. Scatterplot with unadjusted linear regression relationship between preoperative posterior tibial slope and postoperative residual posterior tibial translation (PTT). Gray shaded area represents 95% confidence region for the regression line. There was no significant correlation between the preoperative posterior tibial slope (x-axis) and postoperative posterior tibial translation (y-axis) ($R = -0.115$, P = .249).

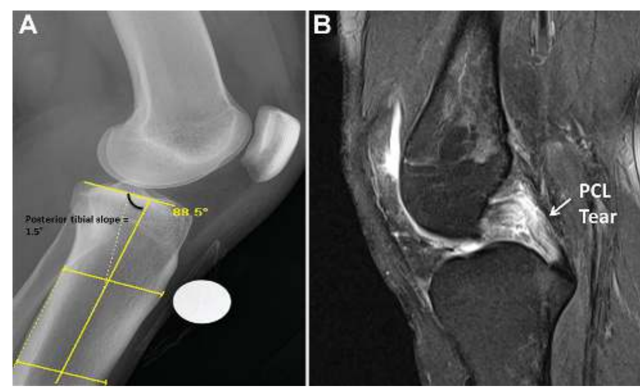

Figure 5. (A) Tibial slope measurement of a patient with a PCL tear reveals a decreased posterior tibial slope measuring 1.5°. (B) T2-weighted sagittal view on magnetic resonance imaging demonstrates an acute grade III PCL tear. PCL, posterior cruciate ligament.

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 after DB PCLR. Thus, we predict that surgical treatment for grade III isolated or combined PCL injuries with DB PCLR may reduce the risk of recurrent graft laxity for patients with flattened native posterior tibial slopes.

In the current study, the mean slope for PCL-injured knees was 5.9°, which is lower than previous reports of 8.0°.[8] Previous studies investigated the influence of sagittal tibial slope on knee kinematics, native ligament force, and PCLR graft laxity.[1,6,8,17,19] The majority of studies suggested that increasing native posterior tibial slope by an anterior opening wedge osteotomy may supplement soft tissue reconstruction, improve knee stability, and protect native and reconstructed PCLs.[1,6,7,17]

Only 1 previous clinical study investigated the correlation of posterior tibial slope and SB PCLR graft laxity and reported that decreased tibial slope (mean, 8.0°) was significantly correlated with increased PTT on kneeling stress radiographs at a mean follow-up of 103 months.[8] In contrast, the unique findings of the current study showed that a flattened preoperative tibial slope had no effect on postoperative PTT after DB PCLR at 18.5 months. We acknowledge the possibility that graft laxity may occur over the long term. Our results allude to this finding such that length to follow-up was a significant risk factor for increased postoperative SSD PTT. However, these findings serve to highlight the short-term potential of DB PCLR in reducing the risk of recurrent graft laxity for patients with flattened native tibial slopes. We suggest that further studies be performed to evaluate the effects of posterior tibial slope and DB PCLR graft laxity after long-term follow-up.

The findings of this study suggest that PCL stability can be achieved after DB PCLR despite a less-than-average preoperative amount of posterior tibial slope (<6°). In addition, we found that combined PCLR (with other concurrent knee ligament reconstructions) resulted in less laxity than isolated DB PCLR. We theorize that this may be due to the fact that a combined injury required additional surgery to stabilize the knee, which may contribute to more inflammation after surgery and a potentially more stable knee. Therefore, we suggest 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 owing to the awareness of the study hypothesis by the research team performing the radiographic measurements. Since the patient cohort was taken from 1 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. This study is also limited by the relatively short-term follow-up, and our results cannot be extrapolated to predict graft laxity over long-term durations.

CONCLUSION

Graft laxity, determined by PTT on posterior kneeling stress radiographs, was not influenced by decreased posterior tibial slope after DB PCLRs. The observed results in the current study support the use of DB PCLR. Future studies should be conducted to compare the effect of tibial slope after SB PCLR and DB PCLR at long-term follow-up.

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