Bernhardson, A. S., DePhillipo, N., Daney, B. T., Kennedy, M. I., Aman, Z. S., LaPrade, R. F. (2019). Posterior Tibial Slope and Risk of Posterior Cruciate Ligament Injury. *American Journal of Sports Medicine, 47*, 312-317

Posterior Tibial Slope and Risk of Posterior Cruciate Ligament Injury

Abstract

Background: Recent biomechanical studies have identified sagittal plane posterior tibial slope as a potential risk factor for posterior cruciate ligament (PCL) injury because of its effects on the kinematics of the native and surgically treated knee. However, the literature lacks clinical correlation between primary PCL injuries and decreased posterior tibial slope.

Purpose/Hypothesis: The purpose of this study was to retrospectively compare the amount of posterior tibial slope between PCL injured patients and an age/gender matched PCL intact controls. It was hypothesized that patients with PCL injuries would have a significantly decreased amount of posterior tibial slope compared to patients without PCL injuries.

Study Design: Case-control study; Level of evidence, 3.

Methods: Patients who underwent a primary PCL reconstruction without ACL injury between 2010 and 2017 by a single surgeon were retrospectively analyzed. Measurements of posterior tibial slope were performed using the lateral radiographs of both PCL injured patients and matched controls without clinical or MRI evidence of ligamentous injury. Mean values of posterior tibial slope were compared between the two groups. Interrater and intrarater agreement was assessed for the tibial slope measurement technique using a two-way random-effects model to calculate the intraclass correlation coefficient (ICC).

Results: One hundred four patients with PCL tears met the inclusion criteria and 104 control patients were matched to the PCL injured group according to age and gender. There were no significant differences in patient age *(P=.*166), gender *(P=.*345), or BMI *(P=.*424) between the PCL injured and control groups. Of the PCL tear cohort, 91 patients (87.5%) sustained a contact mechanism of injury, while 13 patients (12.5%) reported a noncontact mechanism of injury. The mean posterior tibial slope was 5.7 $\pm$ 2.1 degrees (95% confidence interval [CI]: 5.3˚, 6.1˚) and 8.6 $\pm$ 2.2 degrees (95% CI: 8.1˚, 9.0˚) for the PCL injured and matched control groups, respectively (*P*<.0001). Subgroup analysis of the PCL injured patients according to mechanism of injury demonstrated significant differences in posterior tibial slope between noncontact (4.6 $\pm$ 1.8˚) and contact (6.2 $\pm$ 2.2˚) injuries for all PCL tear patients (*P*=.013) and among patients with isolated PCL tears (*P*=.003). The tibial slope measurement technique was highly reliable, with an ICC of 0.852 for interrater and an ICC of 0.872 for intrarater reliability.

Conclusion: A decreased posterior tibial slope was associated with PCL tear patients compared to age and gender-matched control patients with intact PCLs. Decreased tibial slope appears to be a risk factor for primary PCL injury. However, further clinical research is needed to assess if decreased posterior tibial slope affects posterior knee stability and outcomes following PCL reconstructions.

Keywords: posterior cruciate ligament; tibial slope; radiographs; posterior knee instability

INTRODUCTION

As the primary restraint to posterior tibial translation (PTT), the posterior cruciate ligament (PCL) is susceptible to injury by posteriorly directed forces on the proximal tibia.[7, 22] Although the mechanisms of isolated PCL injury have been well described, there is a paucity in the literature regarding the anatomic geometry of the knee joint and its underlying association with the risk of PCL injury. Recent biomechanical and clinical investigations have identified sagittal plane posterior tibial slope as a potential risk factor for anterior cruciate ligament injury because of its substantial effects on the kinematics of the native and surgically treated knee.[10-13, 26]

The average native tibial slope has previously been described as 7-10° posteriorly and is suggested to have a significant impact on *in situ* forces experienced by the cruciate ligaments.[11, 18, 21] Increased posterior tibial slope has been reported to alter the kinematics of the knee joint by anteriorly shifting the resting position of the tibia and subsequently increasingly the *in situ* forces on the anterior cruciate ligament (ACL).[4, 8, 28, 29] Furthermore, increased posterior tibial slope has been directly correlated to higher anterior tibial translation (ATT), predisposing patients to ACL injury.[6, 8] In contrast, increased posterior tibial slope counteracts PTT and reduces the stress placed on the native PCL.[1, 12, 20] However, in PCL reconstructed knees, a decreased posterior tibial slope is correlated with significantly higher residual PTT and lower reduction PTT.[12] Therefore, it is believed that there is a delicate “safe zone” regarding the optimal degree of posterior tibial slope to protect both cruciate ligaments from undesirable forces.

Although the association between tibial slope and ACL injury has been well studied, literature regarding the impact of decreased posterior tibial slope and its associated risk for primary PCL injury is limited. Evaluation of native anatomic factors and demographic factors may aid in determining the impact of decreased posterior tibial slope and the likelihood of sustaining a PCL tear. Therefore, the purpose of this study was to retrospectively compare the amount of posterior tibial slope between PCL injured patients and age/gender matched PCL intact controls. It was hypothesized that patients with PCL injuries would have a significantly decreased amount of posterior tibial slope compared to patients without PCL injuries.

METHODS

Study Design

Following Institutional Review Board approval, patients who underwent primary PCL reconstruction between 2010 and 2017 by a single surgeon (R.F.L.) and had available plain radiographs were retrospectively analyzed. Posterior kneeling stress radiographs were obtained on all patients and indication for a PCL reconstruction was a side-to-side difference in posterior tibial translation of ≥ 8 mm (Figure 1).[15, 25] 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 failed previous PCL reconstructions, patients with concomitant ACL and PCL injuries, and patients who had undergone a prior 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). In addition, a PCL intact control group was built to include patients without a clinical history and MRI evidence of ligamentous injury and a physical exam with no evidence of ligament instability. Controls were matched according to age and gender of the PCL injured cohort. Controls were excluded if they had any other pathologic or congenital condition known to affect tibial slope angulation, including but not limited to congenital genu recurvatum and rheumatoid arthritis.

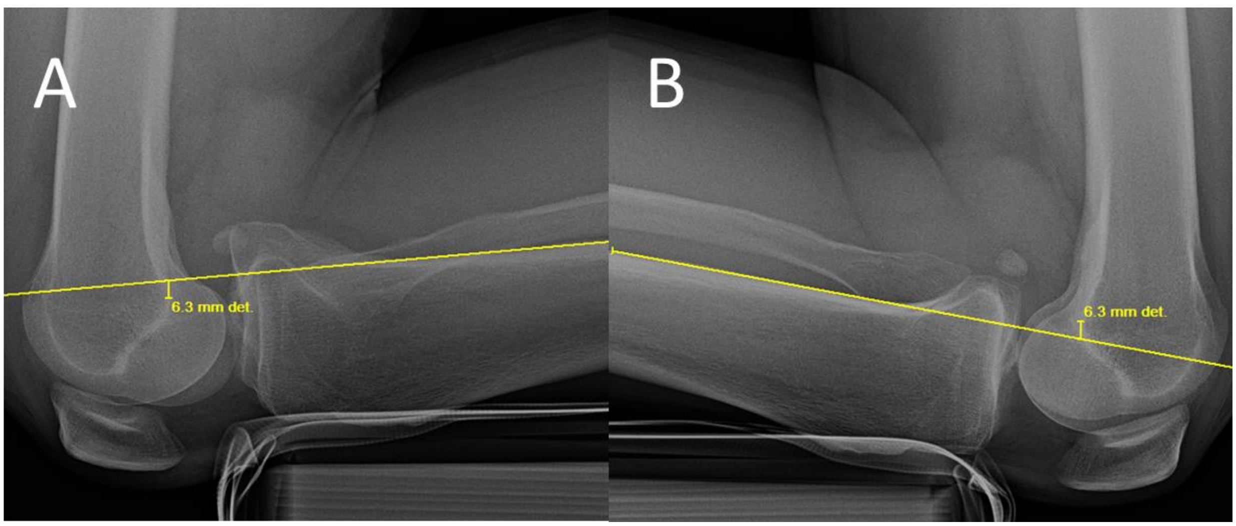

Figure 1. Posterior kneeling stress radiographs. A) Lateral radiograph of injured right knee reveals 6.3 mm of posterior tibial translation compared to B) lateral radiograph of uninjured left knee with 6.3 mm of anterior tibial translation, indicating a complete PCL tear with a side-to-side difference of 12.6 mm of posterior tibial translation.

Imaging Evaluation

Posterior knee stress radiographs, clinical examination, EUA, and arthroscopic procedures were reviewed to determine the presence of a PCL tear and concomitant pathologies. Two independent raters (*A.S.B., B.T.D.*) evaluated the preoperative lateral radiographs of the PCL injured (n=104) and control (n=104) groups to measure the amount of posterior tibial slope according to a previously validated technique.[27] Additionally, a third rater (*N.N.D.*) was chosen to measure a random sample (n=65) of the entire cohort to analyze interrater reliability among 3 different raters. All raters were blinded to the existing knee pathology of all patients, thereby decreasing potential measurement bias.

Posterior tibial slope was measured by first marking points 5 and 15 cm distal to the joint line on the anterior and posterior tibial cortices. A line was drawn to connect the two points marked at 5 cm, and again for the two points marked at 15 cm. The calculated, respectively, and the tibial proximal anatomical axis was drawn to intersect through both midpoints. The degree of posterior 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).[27]

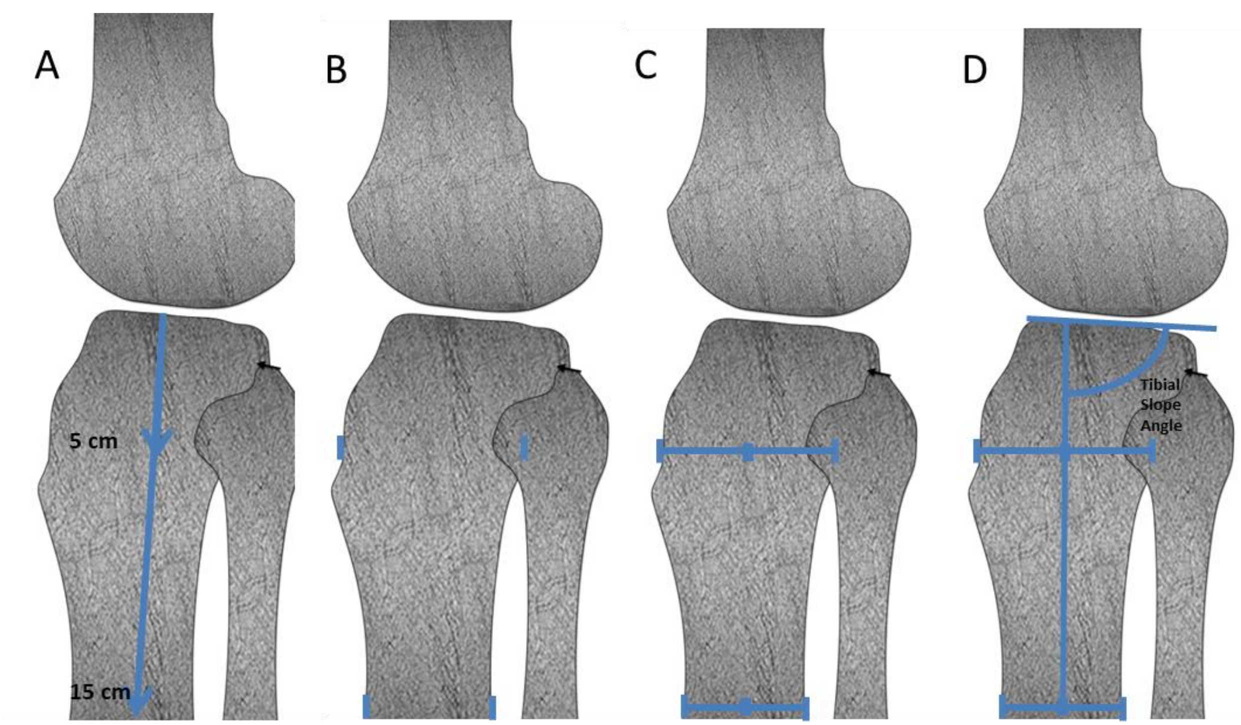

Figure 2. Schematic illustration demonstrating the described measurement technique for calculating

sagittal plane tibial slope. A) First, the tibial joint line was located and a line was drawn 5 cm distal and a second line 15 cm distal. B) Next, the anterior and posterior tibial cortices at both locations were marked and C) a line was drawn connecting the 2 points between the anterior and posterior tibial cortices at 5 cm distal and then at 15 cm distal and the center point on the proximal tibia at both locations was calculated. D) Using an angle tool (or Cobb tool) on an imaging software system, a vertical line was drawn connecting the 2 center points on the proximal tibia and a second horizontal line was drawn parallel to the joint surface. Lastly, the resultant angle was subtracted from 90 to determine the posterior tibial slope angle (in degrees).

Statistical Analysis

Interrater and intrarater agreement was assessed for radiographic measurements using a two-way random-effects model to calculate the intraclass correlation coefficient (ICC). The ICC values were interpreted as follows: ICC < 0.40 = poor agreement; 0.4 < ICC < 0.75 = fair to good agreement; ICC > 0.75 = excellent agreement.[9] Paired *t*-tests were used to compare the mean posterior tibial slope and the mean difference between posterior tibial slope for the PCL injured group compared to the control group. Additionally, independent samples *t*-tests were performed for subgroup analysis comparing isolated and combined PCL injuries and noncontact and contact PCL injuries. All data were analyzed using SPSS Statistics Version 22 (IBM, Armonk, New York, USA), with an alpha level set at .05 for statistical significance.

RESULTS

Patient demographics for the injured and control cohorts are presented in Table 1. One-hundred four patients with PCL tears met the inclusion criteria and 104 control patients were matched to the PCL injured group according to age and gender. There were no significant differences in patient age *(P* = .166), gender *(P* = .345), or BMI *(P* = .424) between the control and PCL injured groups. Patient injury characteristics are presented in Figure 3.

Each patient with a PCL tear underwent an arthroscopic double-bundle reconstruction technique.[3, 17] Of the PCL patient cohort, 50 had an acute (≤ 6 weeks) injury and 54 had a chronic (> 6 weeks) injury at the time of imaging and evaluation. Sixty-five patients had combined extra-articular ligament injuries with the PCL tear, while isolated PCL tears were identified in 39 patients. The majority of PCL injured patients (n=91) reported a contact mechanism (i.e. fall onto a flexed knee) at the time of injury (Table 3). Type of sport is presented in figure 3.

The mean posterior tibial slope was 5.7 ± 2.1 degrees (95% confidence interval [CI]: 5.3˚, 6.1˚) and 8.6 ± 2.2 degrees (95% CI: 8.1˚, 9.0˚) for the PCL injured and matched control groups, respectively *(P* < .0001) (Figure 4; Table 2). When evaluating the reliability of tibial slope measurement technique, it was found that the interrater and intrarater agreement was excellent, with an ICC of 0.852 for interrater reliability and an ICC of 0.872 for intrarater reliability. Additionally, subgroup analysis of PCL injured patients according to mechanism of injury demonstrated a significant difference in posterior tibial slope between noncontact and contact injuries (*P* = .013) for all PCL tear patients and among patients with isolated PCL tears (*P* = .003) (Table 3).

Clinical Characteristics	**Total**	**Male**	**Female**
PCL Tears			
Gender	n = 104	n = 80 (77%)	n = 24 (23%)
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 = 65	n = 52	n = 13
Ligament Intact Controls			
Gender	n = 104	n = 74 (71%)	n = 30 (29%)
Age (years)*	34.4 ± 17.2	32.3 ± 15.0	39.6 ± 18.2
BMI (kg/m^2)*	25.0 ± 3.9	25.4 ± 4.3	23.9 ± 2.7

Table 1. Demographics and clinical characteristics of the PCL injured patients and ligament intact controls. Controls were matched according to age and gender of the PCL injured cohort. BMI: body mass index. *Mean ± standard deviation.

Table 2. Mean posterior tibial slope (in degrees) for PCL tear patients (n=104) and ligament intact controls (n=104). *Mean ± standard deviation. †Statistical significance = *P* < .05. N/A: not applicable.

	PCL Tear	**Control**	***P* Value**
Posterior tibial slope*	$5.7 \pm 2.1^{\circ}$	$8.6 \pm 2.2^{\circ}$	.0001†
Standard error of the mean (SEM)	0.20	0.22	N/A

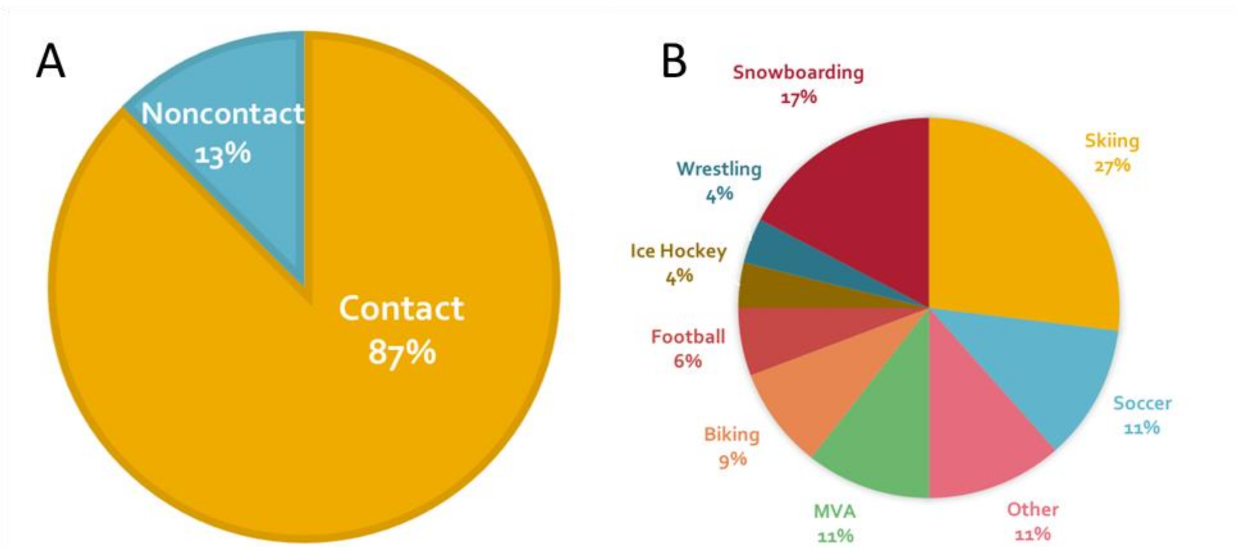

Figure 3. Patient injury characteristics for PCL tear patients (n=104). A) Mechanism of injury, B) Type of sport/activity during injury. MVA: motor vehicle accident.

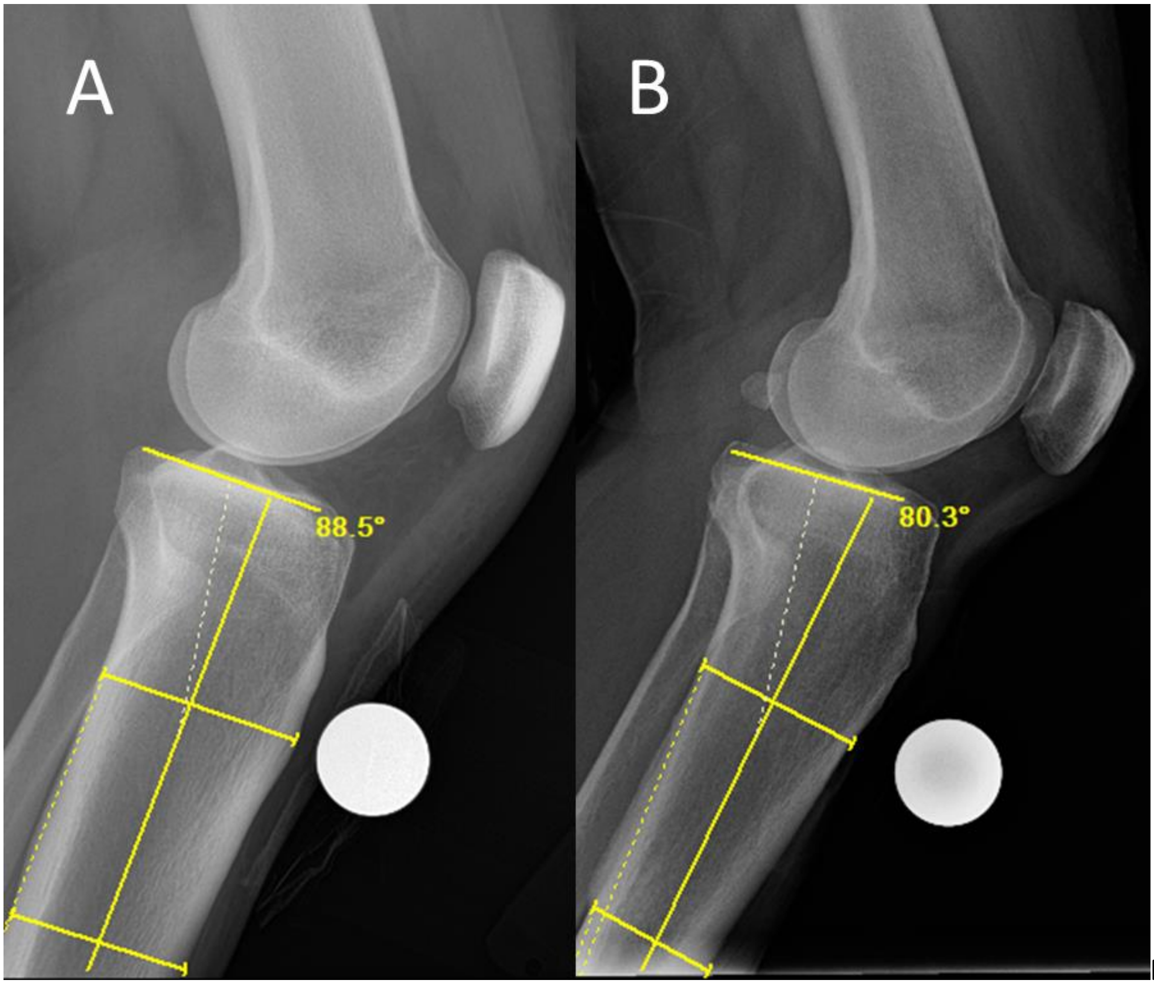

Figure 4. Tibial slope measurement comparison. A) Left knee lateral radiograph of a patient with a PCL injury reveals a decreased posterior tibial slope measuring 1.5 degrees compared to B) left knee lateral radiograph of a PCL intact control patient with a normal posterior tibial slope measuring 9.7 degrees. All controls patients were matched according to age and gender of the PCL injured patients.

Table 3. Mean posterior tibial slope for overall (n=104), isolated (n=39), and combined (n=65) PCL tear patients, grouped according to mechanism of injury (noncontact, n= 13; contact, n=91). *Mean ± standard deviation. †Combined PCL Tear: PCL/MCL; PCL/FCL; PCL/posterolateral corner injury. **Statistical significance = $P < .05$.

Mechanism of Injury	Noncontact	Contact	*P* Value
Overall PCL Tear*	4.6 ± 1.8˚	6.2 ± 2.2˚	.013**
Isolated PCL Tear*	4.0 ± 0.8˚	6.6 ± 2.4˚	.003**
Combined PCL Tear*†	4.8 ± 2.0˚	5.9 ± 2.0˚	.167

DISCUSSION

The main finding of this study was that decreased sagittal plane posterior tibial slope was associated with PCL tears compared to cruciate ligament intact controls. The majority of patients with PCL injuries sustained a contact mechanism with a posteriorly directed force to the proximal tibia. In addition, patients with noncontact PCL injuries had significantly decreased posterior tibial slope compared to contact PCL injuries.

The findings of the current study suggest that a flattened tibial slope of approximately < 6 degrees may increase the force on the PCL and lead to a higher rate of PCL injury. Shelbourne et al.[23] modeled cruciate force and found that a 1 degree increase in posterior tibial slope decreased PCL force by 6 N while also noting an increase in PCL force when slope was decreased during squatting. At tibial resting position, Griffin et al.[10] noted that biomechanically increased tibial slope is beneficial for restoring PCL stability and decreasing posterior tibial translation when applying axial loads and a simulated posterior drawer. The authors concluded that increased posterior tibial slope was protective for PCL deficient knees but did not examine decreased slope and its impact on tibial sag or tibial position.[10]

Biomechanical forces at the time of injury may help explain our finding of decreased posterior tibial slope for patients with noncontact and isolated PCL injuries compared to contact and combined PCL injuries ($P < .01$). Patients with a normal tibial slope or increased tibial slope may require larger force at the time of injury in order to overcome the protective effect of posterior tibial slope on PCL injuries.[10, 12] Previous laboratory research has shown that increasing posterior tibial slope via tibial osteotomy in PCL-deficient knees reduces tibial sag by shifting the resting position of the tibia anteriorly.[10, 11] Similarly, Singerman et al.[24] conducted a biomechanical study and reported a significant increase in PCL strain with decreasing tibial slope from 10˚ to 5˚ following total knee arthroplasty with an opening wedge tibial osteotomy ($P < .0001$). In contrast, Feucht et al.[8] reported in a systematic review of ACL literature that an increased posterior tibial slope represents a risk factor for noncontact ACL injuries. This theory supports our findings of increased posterior tibial slope in patients with combined, contact PCL injuries compared to isolated, noncontact PCL injuries.[14] Thus, patients with a decreased tibial slope who sustain a noncontact, posteriorly directed moment (i.e. landing from a jump, running deceleration, etc.) may be at higher risk of PCL injury based upon their bony anatomy.[8, 12, 14] However, further research with larger sample size in both groups is needed to corroborate this clinical correlation.

The associated findings of primary PCL injury in > 100 patients with a decreased tibial slope appears to be a unique clinical finding that has yet to be fully investigated in the current literature. Although the association of sagittal plane tibial slope and ACL injury has been well studied[5, 14, 18, 29], literature regarding the impact of decreased posterior tibial slope and its associated risk for primary PCL injury is limited. After high tibial osteotomy, studies have highlighted the effect of increasing posterior tibial slope and the resultant increase in knee stability of PCL deficient knees.[2, 11, 16, 19] Further, a recent study has identified a decreased posterior tibial slope as a factor in increased posterior tibial translation in single-bundle PCL reconstructions on follow-up kneeling PCL stress radiographs.[12] Additionally, authors noted that these results were irrespective of patient gender and number of ligaments addressed during PCL reconstruction.[12] [12] No study to date has examined the loading experienced in a single bundle or double bundle PCL graft when subjected to loading conditions at varying slopes and flexion angles which could reveal an ideal slope or range of slopes that may be protective of a reconstructed PCL. Based on existing information, posterior tibial slope may impact PCL reconstructed knees and should be closely examined perioperatively prior to PCL reconstruction.

We acknowledge some limitations to our study. The injury patterns in this cohort included both isolated and combined PCL injuries, which could potentially affect the interpretation of the tibial slope measurements. Further, the use of plain radiographs as opposed to the more recently described use of MRI to measure tibial slope incorporating the meniscus, may change the existing slope with regard to the soft tissues. However, the use of plain radiographs to measure tibial slope is clinically feasible and has been shown to be highly reliable and reproducible.

Conclusion

A decreased posterior tibial slope was associated with PCL tear patients compared to age and gender matched control patients with intact PCLs. Decreased tibial slope appears to be a risk factor for primary PCL injury. However, further clinical research is needed to assess if decreased posterior tibial slope affects posterior knee stability and outcomes following PCL reconstructions.

References

1. Agneskirchner JD, Hurschler C, Stukenborg-Colsman C, Imhoff AB, Lobenhoffer P. Effect of high tibial flexion osteotomy on cartilage pressure and joint kinematics: a biomechanical study in human cadaveric knees. Winner of the AGA-DonJoy Award 2004. *Arch Orthop Trauma Surg.* 2004;124(9):575-584.
2. Arthur A, LaPrade RF, Agel J. Proximal tibial opening wedge osteotomy as the initial treatment for chronic posterolateral corner deficiency in the varus knee: a prospective clinical study. *Am J Sports Med.* 2007;35(11):1844-1850.
3. Chahla J, Nitri M, Civitarese D, Dean CS, Moulton SG, LaPrade RF. Anatomic Double-Bundle Posterior Cruciate Ligament Reconstruction. *Arthrosc Tech.* 2016;5(1):e149-156.
4. Christensen JJ, Krych AJ, Engasser WM, Vanhees MK, Collins MS, Dahm DL. Lateral Tibial Posterior Slope Is Increased in Patients With Early Graft Failure After Anterior Cruciate Ligament Reconstruction. *Am J Sports Med.* 2015;43(10):2510-2514.
5. Dean CS, Liechti DJ, Chahla J, Moatshe G, LaPrade RF. Clinical Outcomes of High Tibial Osteotomy for Knee Instability: A Systematic Review. *Orthop J Sports Med.* 2016;4(3):2325967116633419.
6. Dejour H, Bonnin M. Tibial translation after anterior cruciate ligament rupture. Two radiological tests compared. *J Bone Joint Surg Br.* 1994;76(5):745-749.
7. DePhillipo NN, Cinque ME, Godin JA, Moatshe G, Chahla J, LaPrade RF. Posterior Tibial Translation Measurements on Magnetic Resonance Imaging Improve Diagnostic Sensitivity for Chronic Posterior Cruciate Ligament Injuries and Graft Tears. *Am J Sports Med.* 2017:363546517734201.
8. Feucht MJ, Mauro CS, Brucker PU, Imhoff AB, Hinterwimmer S. The role of the tibial slope in sustaining and treating anterior cruciate ligament injuries. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(1):134-145.
9. Fleiss JL, Chilton NW, Park MH. Inter- and intra-examiner variability in scoring supragingival plaque: II. Statistical analysis. *Pharmacol Ther Dent.* 1980;5(1-2):5-9.
10. Giffin JR, Stabile KJ, Zantop T, Vogrin TM, Woo SL, Harner CD. Importance of tibial slope for stability of the posterior cruciate ligament deficient knee. *Am J Sports Med.* 2007;35(9):1443-1449.
11. Giffin JR, Vogrin TM, Zantop T, Woo SL, Harner CD. Effects of increasing tibial slope on the biomechanics of the knee. *Am J Sports Med.* 2004;32(2):376-382.
12. Gwinner C, Weiler A, Roider M, Schaefer FM, Jung TM. Tibial Slope Strongly Influences Knee Stability After Posterior Cruciate Ligament Reconstruction: A Prospective 5- to 15-Year Follow-up. *Am J Sports Med.* 2017;45(2):355-361.
13. Hashemi J, Chandrashekar N, Mansouri H, et al. Shallow medial tibial plateau and steep medial and lateral tibial slopes: new risk factors for anterior cruciate ligament injuries. *Am J Sports Med.* 2010;38(1):54-62.
14. Hohmann E, Bryant A, Reaburn P, Tetsworth K. Is there a correlation between posterior tibial slope and non-contact anterior cruciate ligament injuries? *Knee Surg Sports Traumatol Arthrosc.* 2011;19 Suppl 1:S109-114.

15. Jackman T, LaPrade RF, Pontinen T, Lender PA. Intraobserver and interobserver reliability of the kneeling technique of stress radiography for the evaluation of posterior knee laxity. *Am J Sports Med.* 2008;36(8):1571-1576.

16. Jacobi M, Wahl P, Jakob RP. Avoiding intraoperative complications in open-wedge high tibial valgus osteotomy: technical advancement. *Knee Surg Sports Traumatol Arthrosc.* 2010;18(2):200-203.

17. LaPrade RF, Cinque ME, Dornan GJ, et al. Double-Bundle Posterior Cruciate Ligament Reconstruction in 100 Patients at a Mean 3 Years' Follow-up: Outcomes Were Comparable to Anterior Cruciate Ligament Reconstructions. *Am J Sports Med.* 2018;46(8):1809-1818.

18. Mitchell JJ, Cinque ME, Dornan GJ, et al. Primary Versus Revision Anterior Cruciate Ligament Reconstruction: Patient Demographics, Radiographic Findings, and Associated Lesions. *Arthroscopy.* 2018;34(3):695-703.

19. Naudie DD, Amendola A, Fowler PJ. Opening wedge high tibial osteotomy for symptomatic hyperextension-varus thrust. *Am J Sports Med.* 2004;32(1):60-70.

20. Petrigliano FA, Suero EM, Voos JE, Pearle AD, Allen AA. The effect of proximal tibial slope on dynamic stability testing of the posterior cruciate ligament- and posterolateral corner-deficient knee. *Am J Sports Med.* 2012;40(6):1322-1328.

21. Schatka I, Weiler A, Jung TM, Walter TC, Gwinner C. High tibial slope correlates with increased posterior tibial translation in healthy knees. *Knee Surg Sports Traumatol Arthrosc.* 2017.

22. Schulz MS, Russe K, Weiler A, Eichhorn HJ, Strobel MJ. Epidemiology of posterior cruciate ligament injuries. *Arch Orthop Trauma Surg.* 2003;123(4):186-191.

23. Shelburne KB, Kim HJ, Sterett WI, Pandy MG. Effect of posterior tibial slope on knee biomechanics during functional activity. *J Orthop Res.* 2011;29(2):223-231.

24. Singerman R, Dean JC, Pagan HD, Goldberg VM. Decreased posterior tibial slope increases strain in the posterior cruciate ligament following total knee arthroplasty. *J Arthroplasty.* 1996;11(1):99-103.

25. Spiridonov SI, Slinkard NJ, LaPrade RF. Isolated and combined grade-III posterior cruciate ligament tears treated with double-bundle reconstruction with use of endoscopically placed femoral tunnels and grafts: operative technique and clinical outcomes. *J Bone Joint Surg Am.* 2011;93(19):1773-1780.

26. Todd MS, Lalliss S, Garcia E, DeBerardino TM, Cameron KL. The relationship between posterior tibial slope and anterior cruciate ligament injuries. *Am J Sports Med.* 2010;38(1):63-67.

27. Utzschneider S, Goettinger M, Weber P, et al. Development and validation of a new method for the radiologic measurement of the tibial slope. *Knee Surg Sports Traumatol Arthrosc.* 2011;19(10):1643-1648.

28. Voos JE, Suero EM, Citak M, et al. Effect of tibial slope on the stability of the anterior cruciate ligament-deficient knee. *Knee Surg Sports Traumatol Arthrosc.* 2012;20(8):1626-1631.

29. Yamaguchi KT, Cheung EC, Markolf KL, et al. Effects of Anterior Closing Wedge Tibial Osteotomy on Anterior Cruciate Ligament Force and Knee Kinematics. *Am J Sports Med.* 2018;46(2):370-377.