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Original Research Article

POSTERIOR TIBIAL SLOPE AND ACL INJURY PATTERN IN INDIAN KNEES A PROSPECTIVE MRI BASED CASE CONTROL OBSERVATIONAL STUDY

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ABSTRACT

Background: Posterior tibial slope (PTS) is an important anatomical factor that may increase anterior tibial translation and predispose to anterior cruciate ligament (ACL) injury. Data on PTS patterns and its relation to chronicity of ACL tears in hospital-based populations are limited. The aim is to compare medial and lateral PTS between ACL-injured and control knees and to evaluate the distribution of PTS and its relationship with acute versus chronic ACL tears.
Materials and Methods: This prospective observational case–control study included 40 patients with MRI-confirmed ACL tears (cases) and 37 patients without ACL injury (controls), aged 18–50 years, presenting with traumatic knee pain. Standardised clinical examination and knee MRI were performed. Medial and lateral PTS were measured on sagittal MRI using a circle-based tibial axis method. Cases were classified as acute (≤6 weeks) or chronic (>6 weeks) based on symptom duration. Mean PTS values were compared using independent-sample t-tests.
Results: Among ACL-injured patients, 55.0% were aged 30–50 years and 82.5% were male; 57.5% had left-sided involvement and 55.0% had non-contact injury, with 80.0% presenting as chronic tears. In ACL-deficient knees, medial PTS was 5–10° in 67.5% and >10° in 17.5%; lateral PTS was 5–10° in 62.5% and >15° in 7.5%. Mean medial (7.82 ± 2.56° vs 5.91 ± 4.49°, P = 0.029) and lateral PTS (10.53 ± 3.46° vs 6.24 ± 5.15°, P < 0.001) were significantly higher in ACL cases than controls. Medial and lateral PTS did not differ significantly between acute and chronic ACL tears.
Conclusion: ACL-injured knees demonstrated significantly higher medial and lateral PTS than control knees, supporting PTS as an intrinsic risk factor for ACL injury. Within the ACL group, PTS was not associated with tear chronicity.
Keywords: anterior cruciate ligament, posterior tibial slope, medial tibial slope, lateral tibial slope, MRI knee, acute ACL tear, chronic ACL tear.

INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most common ligamentous injuries of the knee and leads to pain, instability, reduced sports participation and a higher risk of early knee osteoarthritis over time.[1] In many patients, especially those with non-contact or low-energy mechanisms, intrinsic anatomical factors may play a major role in predisposing the knee to ACL failure and to subsequent graft rupture after reconstruction.[2]

Posterior tibial slope (PTS) defined as the angle between the tibial plateau and the tibial shaft axis in the sagittal plane has emerged as an important osseous factor influencing anterior translation of the tibia and in-situ loading of the ACL.[3] Biomechanical and clinical work suggests that even modest increases in PTS can increase anterior shear forces across the tibiofemoral joint, resulting in greater ACL strain and a higher likelihood of primary rupture and graft failure after reconstruction.[4]

MRI-based case–control studies have compared medial and lateral PTS between ACL-injured patients and ligament-intact controls and generally reported steeper slopes in the injured group, particularly on the lateral side.[1] An Indian case–control series found significantly higher lateral PTS in ACL-deficient knees compared with controls with a smaller difference medially suggesting that lateral slope may be more sensitive as a practical marker of ACL risk.[1] A large systematic review and meta-analysis pooling more than ten thousand knees confirmed that increased PTS, whether measured medially or laterally, is a significant risk factor for primary ACL injury when compared with ACL-intact controls.[2]

Evidence also indicates that increased PTS is associated with graft failure after ACL reconstruction. A long-term clinical trial reported that patients who required revision for graft rupture had greater tibial slope than those without failure and this association was observed irrespective of graft choice, supporting PTS as an independent intrinsic risk factor.[4] Another study that used the Hudek MRI method to measure medial and lateral PTS found that only increased lateral PTS with a cut-off around 6° was associated with early graft failure within two years of primary ACL reconstruction, whereas medial PTS was similar between revision and non-revision groups.[5] A recent systematic review synthesised multiple studies and observed that PTS tended to be lowest in knees with intact ACL, intermediate in primary ACL tears and highest in failed ACL reconstructions, suggesting a dose–response relationship across this continuum.[3]

However most available work has focused on comparing ACL injured patients with intact controls or on contrasting failed versus successful reconstructions. Less attention has been given to how PTS is distributed within a typical ACL-injured hospital cohort and whether medial or lateral slope differs between acute and chronic ACL tears at presentation. Simple MRI-based descriptions of PTS categories in ACL-deficient knees and their relationship with injury chronicity, remain relatively limited.[2,6]

The present prospective MRI-based case–control study was designed with two main objectives, First to compare medial and lateral posterior tibial slope between ACL-injured knees and control knees without ACL tears. Then to describe the distribution of PTS categories in ACL-deficient knees and to evaluate whether medial or lateral PTS differs between acute and chronic ACL tears at presentation.

MATERIALS AND METHODS

This was a prospective observational case–control study conducted in the Department of Orthopaedics of a tertiary care teaching hospital over 18 months, from October 2023 to March 2025. Patients presenting to the outpatient clinic with a history of traumatic knee pain were evaluated clinically and radiologically. Those fulfilling the eligibility criteria were enrolled consecutively either into the ACL-injured group (cases) or the control group. The case group consisted of 40 patients aged between 18 and 50 years with MRI-confirmed partial or complete ACL tear. The control group included 37 patients in the same age range who had traumatic knee pain but no ACL injury on MRI.

Patients were included if they had age more than 18 years and less than 50 years, a clear history of trauma to the knee and for the case group, definite ACL tear on MRI. Both contact and non-contact mechanisms of injury were accepted. Patients were excluded if they had any previous surgery on the involved knee, grade 2 or higher osteoarthritic changes on radiographs, peri-articular or intra-articular fracture around the knee, tumour or cyst of proximal tibia, congenital deformity around the knee, known inheritable musculoskeletal disorder, or chondromalacia patella grade 3 or higher.

All patients underwent detailed history and physical examination by the same orthopaedic team. Age, sex, side involved, mechanism of trauma and duration of symptoms were recorded. Duration of injury was used to classify ACL tears into acute and chronic; presentation within 6 weeks of trauma was labelled as acute ACL tear, while presentation after 6 weeks was taken as chronic ACL tear. Clinical knee examination included standard tests for cruciate and meniscal injuries such as anterior and posterior drawer tests, Lachman test, pivot shift and McMurray test. Findings were used to support the diagnosis and to decide MRI evaluation.

Plain radiographs of the affected knee in anteroposterior and lateral views were obtained in all patients to exclude fractures and to grade osteoarthritis. MRI of the knee joint was then performed using a dedicated knee coil and routine sequences. ACL status was confirmed as intact or torn by the reporting radiologist. Only those patients who satisfied all inclusion and exclusion criteria and had complete imaging were retained for final analysis.

Posterior tibial slope was measured on sagittal MRI using a circle based method to define the tibial axis. First, the mid-sagittal slice of the tibia showing the tibial attachment of the posterior cruciate ligament, intercondylar eminence and concave anterior and posterior cortices was selected. Two overlapping circles were drawn within the proximal tibia; the proximal circle touched the anterior, posterior and superior cortices and the distal circle had its centre on the most inferior point of the first circle and again touched the anterior and posterior cortices. A line joining the centres of these two circles defined the sagittal longitudinal axis of the proximal tibia. This axis line was then transferred to the slices showing the medial and lateral tibial plateaus. On each plateau a line joining the most superior anterior and posterior points of the articular surface was drawn to represent the plateau slope. A perpendicular line to the tibial axis was constructed and the angle between this perpendicular and the plateau line was recorded as

posterior tibial slope. The angle measured on the medial side was taken as medial posterior tibial slope (MPTS) and that on the lateral side as lateral posterior tibial slope (LPTS). All measurements were performed on the PACS workstation by the same observer to reduce variability.

Data were entered in a spreadsheet and analysed using standard statistical software. Continuous variables, including medial and lateral posterior tibial slope, were expressed as mean ± standard deviation. Categorical variables were expressed as frequency and percentage. Mean medial and lateral PTS values were compared between ACL cases and controls using the independent samples t-test. Within the ACL-injured group, mean PTS values were also compared between acute and chronic tears using the t test. A P value less than 0.05 was considered statistically significant.

RESULTS

Table 1: Background characteristics of ACL-injured patients

Variable	Category	Frequency (n)	Percentage (%)
Age group (years)	18–30	18	45.0
	30–50	22	55.0
Gender	Male	33	82.5
	Female	7	17.5
Affected side	Left	23	57.5
	Right	17	42.5
Type of injury	Contact	18	45.0
	Non-contact	22	55.0
Duration of injury	Acute	8	20.0
	Chronic	32	80.0

[Table 1] shows the baseline characteristics of the 40 ACL-injured patients. Most patients were between 30–50 years of age (55.0%), while 45.0% were in the 18–30-year group. Males constituted the majority (82.5%), with females accounting for 17.5%. The left knee was more commonly affected (57.5%) than the right knee (42.5%). Non-contact mechanisms of injury (55.0%) were slightly more frequent than contact injuries (45.0%). Most ACL tears were chronic at presentation, with 80.0% classified as chronic and only 20.0% as acute [Table 1].

Table 2: Distribution of posterior tibial slope (PTS) in ACL-injured knees

Medial posterior tibial slope (MPTS)		
MPTS category (degrees)	**Frequency (n)**	**Percentage (%)**
< 5	6	15.0
5–10	27	67.5
> 10	7	17.5
Lateral posterior tibial slope (LPTS)		
LPTS category (degrees)	Frequency (n)	Percentage (%)
5–10	25	62.5
10–15	12	30.0
> 15	3	7.5

[Table 2] summarises the distribution of posterior tibial slope among ACL-injured knees. For the medial posterior tibial slope (MPTS), two-thirds of patients (67.5%) had values between 5–10°, while 15.0% had MPTS <5° and 17.5% had MPTS >10°. For the lateral posterior tibial slope (LPTS), most knees (62.5%) had values between 5–10°, 30.0% had LPTS between 10–15° and 7.5% had LPTS >15°. Overall, the majority of ACL-deficient knees demonstrated a moderate medial slope and a relatively steeper lateral slope.

Table 3: Comparison of posterior tibial slope between ACL-injured knees and controls

Tibial slope	ACL cases (n = 40) Mean ± SD*	Controls (n = 37) Mean ± SD	P-value
Medial compartment	7.82 ± 2.56	5.91 ± 4.49	0.029
Lateral compartment	10.53 ± 3.46	6.24 ± 5.15	<0.001

[Table 3] presents the comparison of posterior tibial slope between ACL-injured knees (n = 40) and control knees without ACL tear (n = 37). The mean medial tibial slope was significantly higher in the ACL group (7.82 ± 2.56°) compared with controls (5.91 ± 4.49°; P = 0.029). Similarly, the mean lateral tibial slope was markedly higher in ACL-injured knees (10.53 ± 3.46°) than in control knees (6.24 ± 5.15°; P < 0.001). Thus, both medial and especially lateral posterior tibial slopes were significantly greater in ACL-deficient knees compared with controls.

Table 4: Comparison of posterior tibial slope between acute and chronic ACL tears

Tibial slope	Acute ACL (n = 8) Mean ± SD	Chronic ACL (n = 32) Mean ± SD	P-value‡
Medial PTS (degrees)	7.50 ± 2.30	7.90 ± 2.60	0.40
Lateral PTS (degrees)	10.25 ± 3.10	10.60 ± 3.50	0.45

[Table 4] compares posterior tibial slope between acute (n = 8) and chronic (n = 32) ACL tears. Mean medial PTS was slightly lower in acute tears (7.50 ± 2.30°) than in chronic tears (7.90 ± 2.60°), but this difference was not statistically significant (P = 0.40). Mean lateral PTS was also marginally lower in acute ACL injuries (10.25 ± 3.10°) compared with chronic injuries (10.60 ± 3.50°), with no significant difference (P = 0.45). Therefore, within the ACL-injured group, posterior tibial slope did not differ significantly between acute and chronic tears.

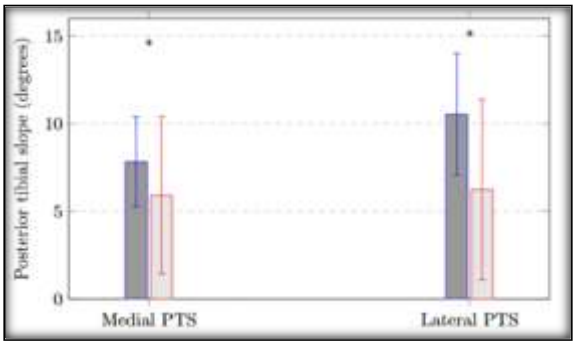

Figure 1: Mean medial and lateral posterior tibial slope in ACL cases and control knees

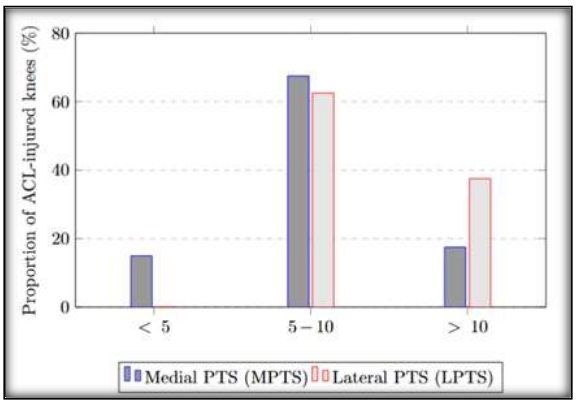

Figure 2: Distribution pattern of posterior tibial slope categories in ACL injured knees

DISCUSSION

In this MRI based case–control study we found that both medial and especially lateral posterior tibial slope were significantly higher in ACL injured knees compared with controls without ACL tear. Mean MPTS in cases was 7.8° and LPTS was 10.5°, while controls had much flatter plateaus. This supports posterior tibial slope as an important intrinsic risk factor for ACL rupture in our population. Our values fall within Asian ranges and are slightly lower than those reported by Ravi Kumar et al. from an Indian ACL deficient cohort where radiographic mean PTS was higher in ACL injured knees than in non injured knees.[6] These findings are in line with large biomechanical and clinical data. Bernhardson and colleagues showed that ACL graft force increases more or less linearly as posterior tibial slope increases, even with small angular changes.[7]

Shelburne et al. also demonstrated that greater slope shifts the tibiofemoral contact point posteriorly and increases anterior tibial translation and ACL loading during functional tasks.[8] Hashemi et al. described steep medial and lateral slopes and shallow medial plateau as structural risk factors for non contact ACL injury, again supporting the concept that bony geometry can predispose to ligament failure.[9]

Our case–control difference in LPTS is also consistent with previous comparative MRI studies. Elmansori et al. reported that both bony and meniscal slopes were higher in ACL injured subjects than in matched controls, with lateral slope showing stronger association.[10]

The systematic review and meta analysis by Hinz et al. in the Orthopaedic Journal of Sports Medicine pooled data across intact ACL, primary ACL tears and failed ACL reconstructions and confirmed that patients with primary or graft failure ACL pathology have significantly steeper medial and lateral PTS compared to intact ACL groups.[11] Our observation that LPTS separation between cases and controls was numerically larger than MPTS is therefore in line with this literature suggesting lateral slope may be the more “aggressive” compartment for ACL risk.

Zeng et al. provided further synthesis in a more recent Journal of ISAKOS systematic review where increased posterior tibial slope was consistently associated with both primary ACL injury and ACL graft failure across radiographic and MRI based studies, with several cohorts highlighting particularly elevated risk when slope exceeded moderate thresholds.[2]

In a prospective randomised ACL reconstruction trial with 10 year follow up, Cruz et al. showed that both autograft and allograft failures had significantly higher mean tibial slope (12°) than non failure knees (≈9–10°) and they concluded that posterior tibial slope is an independent risk factor for graft failure irrespective of graft type.[4] Our mean LPTS in injured knees around 10.5° lies close to the “at risk” zone reported in these series and may therefore have relevance not only for primary injury but also for counselling before reconstruction.

The present study also found no meaningful difference in medial or lateral PTS between acute and chronic ACL tears. This suggests that slope probably acts as a pre injury anatomic risk factor rather than determining how early the patient presents to the hospital. Sevim et al. in a larger OJSM cohort compared side to side PTS differences between acute and chronic ACL deficient knees and similarly reported no clinically important differences, concluding that posterior tibial slope does not seem to influence the timing of presentation, only the occurrence of ACL tear itself.[12] Our findings support that view and indicate that using “acute vs chronic” pattern alone is unlikely to stratify risk based on slope.

From a mechanistic angle, our results fit with studies linking PTS to global sagittal alignment and dynamic loading. Hiranaka et al. showed that increased

posterior tibial slope was associated with a more flexed sagittal knee alignment on long leg radiographs, which may in turn maintain the joint in positions of higher ACL load during daily activity.[13] Bates et al. found that steeper slope correlated with increased peak ACL relevant knee joint loading in robotic simulations of cutting and landing tasks.[14] Taken together, these data explain why even modest differences in LPTS, such as those seen between our cases and controls, may translate into clinically significant differences in cumulative ACL strain over time.

Our study did not formally analyse meniscal bone angle or meniscal slope, but these parameters are now recognised as additional geometric risk modifiers. Deng et al. reported that a steep medial PTS was associated with medial meniscus tears in adolescents while Teixeira Gonçalves Alves et al. found that a reduced meniscal bone angle was a strong predictor of ACL injury.[15,16] Clinically our findings support routine reporting of medial and lateral PTS on knee MRI in young active patients with ACL injury. Zeng's meta analysis and the BMC Musculoskeletal Disorders case control study both suggest that high LPTS is also linked with early ACL graft failure and that slope reducing tibial osteotomy can reduce graft forces in high risk revision cases.[2,5,17] While our current cohort did not include post reconstruction follow up, identifying patients with steep slopes at the index injury stage may help in planning graft choice, tunnel placement, extra articular procedures or even considering slope modification in revision scenarios. This study has limitations as sample size was modest and from a single centre. Only MRI based Hudek circle method was used and we did not compare different radiographic techniques which can shift absolute slope values. We also did not adjust for BMI, activity level or rotational alignment, which can confound the relationship between slope and injury. The consistent direction of effect across our data and multiple external studies suggests that the observed association between higher PTS and ACL rupture is biologically plausible and robust. Overall our 40 patient case–control analysis adds to the growing body of evidence that steeper posterior tibial slope, especially on the lateral side, is an important intrinsic risk factor for ACL injury, but it does not appear to influence whether an ACL tear presents as an acute or chronic case.

CONCLUSION

This prospective MRI-based case–control study showed that medial and especially lateral, posterior tibial slope was significantly higher in ACL-injured knees than in control knees, supporting slope as an important intrinsic risk factor for ACL rupture. Within the ACL group, medial and lateral slopes did not differ between acute and chronic tears, suggesting that PTS mainly influences the occurrence of injury rather than timing of presentation. Routine reporting of medial and lateral PTS on knee MRI may help in risk stratification and counselling and larger studies incorporating meniscal injury pattern, functional outcome and long-term follow-up are needed to clarify its full clinical impact.

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