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Original Article

Varus Alignment, Increased Lateral Posterior Tibial Slope, and Decreased PCL Footprint Angle Are Independently Associated with Isolated Degenerative Medial Meniscus Posterior Root Tears: A Matched Case-Control Study

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ABSTRACT

Objective: The purpose of this study was to investigate the relationship between isolated degenerative medial meniscus posterior root tears (MMPRTs) and varus alignment, lateral and medial posterior tibial slopes (LPTS and MPTS), and the PCL tibial footprint angle (PCL-FPA).

Materials and Methods: This retrospective matched case-control study included 192 patients aged 40–65 years without ACL pathology. Ninety-six patients with MMPRT were matched 1:1 by age and sex with 96 controls, yielding 96 matched pairs. LPTS and MPTS were measured on sagittal MRI using the Hudek technique; PCL-FPA was defined as the angle between the tibial longitudinal axis and the PCL footprint line on MRI; and varus alignment was assessed by measuring the mechanical axis angle on full-length weight-bearing radiographs. Mann-Whitney U and chi-square tests were used for between-group comparisons, and Firth-penalized logistic regression analysis was used to identify independently associated parameters.

Results: Compared with the control group, the MMPRT group demonstrated significantly higher LPTS (10.94±3.25° vs. 7.51±3.03°; $p<0.001$) and varus alignment (4.38±1.77° vs. 2.59±1.51°; $p<0.001$), and significantly lower PCL-FPA (49.95±7.55° vs. 54.62±6.27°; $p<0.001$). MPTS was similar between the groups ($p=0.479$). On multivariable analysis, LPTS (OR=1.497; 95% CI 1.283–1.746; $p<0.001$), varus alignment (OR=2.199; 95% CI 1.656–2.922; $p<0.001$), and PCL-FPA (OR=0.935; 95% CI 0.881–0.992; $p=0.026$) were independently associated with isolated degenerative MMPRT. ROC analysis revealed the highest individual AUC for varus alignment (AUC=0.790; 95% CI 0.724–0.851), while the combined model yielded an AUC of 0.885 (95% CI 0.835–0.929).

Conclusion: Isolated degenerative MMPRT is independently associated with varus alignment, increased LPTS, and decreased PCL-FPA. MPTS was not significantly associated with MMPRT in this ACL-intact cohort. Increased LPTS may reflect altered rotational knee biomechanics related to MMPRT, whereas decreased PCL-FPA may represent a distinct posterior tibial attachment geometry related to the medial meniscus posterior root. Further biomechanical studies and external validation are needed to confirm these findings.

Keywords: Magnetic resonance imaging, Meniscus, Meniscus injuries, Risk factors, Tibial slope, Varus deformity.

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INTRODUCTION

Medial meniscus posterior root tears (MMPRTs) account for approximately 10–21% of meniscal tears and remain an important, potentially underdiagnosed cause of knee dysfunction.[1] Medial meniscus posterior root tears constitute approximately 52% of all meniscal root tears, occur more commonly in women, and typically present in middle age.[1] Current concepts regarding the anatomy, diagnosis, and treatment of meniscal root tears continue to evolve.[2] Disruption of posterior root integrity compromises the ability of the meniscus to convert axial loads into circumferential hoop stresses, resulting in a marked increase in tibiofemoral contact pressure and producing biomechanical changes comparable to those observed after total meniscectomy.[3,4] The resulting loss of functional meniscal support has been associated with accelerated progression of knee osteoarthritis, even in patients without pre-existing radiographic osteoarthritis.[5]

Osseous morphology has increasingly been recognized as an important factor associated with MMPRT. Systematic reviews have identified increased medial posterior tibial slope, varus alignment, and reduced intercondylar dimensions as morphometric features associated with MMPRT.[6,7] However, most previous investigations have focused primarily on tibial slope and coronal alignment, whereas the potential contribution of posterior tibial attachment geometry remains poorly understood. In particular, the relationship between the tibial attachment geometry of the posterior cruciate ligament (PCL) and MMPRT has not previously been investigated. The tibial attachment of the PCL is located approximately 1.0–1.5 cm distal to the joint line, and the center of the medial meniscus posterior root lies only 8.2±0.7 mm from the nearest border of the PCL tibial attachment.[8] This close anatomical relationship raises the possibility that the PCL tibial footprint angle (PCL-FPA) may provide indirect information regarding posterior tibial attachment morphology adjacent to the medial meniscus posterior root. Although attachment-site orientation has been shown to influence enthesis biomechanics in other anatomical structures,[9,10] whether such geometric characteristics are associated with MMPRT remains unknown.

The purpose of this study was to investigate the associations of varus alignment, lateral posterior tibial slope (LPTS), medial posterior tibial slope (MPTS), and PCL-FPA with isolated degenerative MMPRT in an ACL-intact population compared with an age- and sex-matched control group.

MATERIALS AND METHODS

Study Design and Patient Selection

This study was designed as a retrospective matched case-control study. Following institutional review board approval (approval date: 27 February 2026; no. 236), the institutional archive was searched to identify patients who underwent knee MRI between January 2018 and December 2023. The MMPRT group consisted of patients diagnosed with isolated medial meniscus posterior root tears confirmed by arthroscopy or MRI. Of the 96 patients with MMPRT, 56 had arthroscopic confirmation, whereas 40 were diagnosed by MRI alone based on established imaging criteria for posterior root tears, including radial/cleft, ghost, and truncation signs. The control group consisted of individuals who underwent MRI for nonspecific anterior knee pain and had no meniscal root pathology. These patients were selected as controls because they underwent knee MRI using comparable protocols, enabling standardized measurements, while lacking meniscal root pathology.

For the purposes of this study, degenerative MMPRT was defined as a posterior root tear occurring without a history of significant acute knee trauma in patients aged 40–65 years, with MRI findings and, where available, arthroscopic findings consistent with a degenerative rather than an acute traumatic tear. The inclusion criteria were: (1) a diagnosis of isolated MMPRT, (2) availability of adequate-quality sagittal MRI images, and (3) age between 40 and 65 years. The exclusion criteria were: (1) concomitant ACL tear or a history of ACL reconstruction, (2) lateral meniscus root tear, (3) advanced knee osteoarthritis (Kellgren–Lawrence grade 3–4), (4) previous knee surgery, and (5) inflammatory joint disease. A total of 96 patients with MMPRT met these criteria and were included in the study.

Matching Strategy

Age- and sex-matched pairing was performed to ensure demographic comparability between the groups. The institutional database was searched to identify eligible control candidates who met the inclusion criteria. When multiple control candidates of the same age and sex were available for a given MMPRT patient, selection was performed by random sampling. Control selection was performed independently of radiological measurement results. This process yielded 96 matched pairs (192 patients in total).

Imaging Protocol and Radiological Measurements

All patients underwent a standardized knee MRI protocol. Images were obtained in the sagittal, coronal, and axial planes using proton density-weighted fat-suppressed sequences. Varus alignment was assessed by measuring the mechanical axis angle on full-length weight-bearing radiographs. Full-length weight-bearing radiographs were available for all patients and were obtained within a comparable time interval relative to the index MRI using the same standardized acquisition protocol. MRI evaluations and radiographic measurements were performed with the investigators blinded to clinical and group information.

Posterior Tibial Slope Measurement: MPTS and LPTS were measured on sagittal MRI sections using the method described by Hudek et al.[11] The tibial longitudinal axis was determined using the two-circle method, and the posterior tibial slope was measured as the angle between the tangent to the tibial plateau and the line perpendicular to this axis. MPTS and LPTS were measured separately on the medial and lateral tibial plateau sections, respectively (Fig. 1).

PCL Footprint Angle (PCL-FPA): The PCL-FPA was a novel radiological measurement parameter defined in this study. It was measured on the sagittal MRI section in which the PCL tibial attachment was most clearly visualized as the angle between the tibial longitudinal axis and a line drawn parallel to the PCL tibial footprint surface. The tibial longitudinal axis was determined using the two-circle method described by Hudek et al., and the PCL footprint line was drawn parallel to the attachment surface of the PCL fibers on the tibia (Fig. 2).

Varus Alignment: Varus alignment was assessed by measuring the mechanical axis varus angle on full-length weight-bearing radiographs. This angle was defined as the angle between the line extending from the center of the femoral head to the center of the knee joint and the line extending from the center of the knee joint to the midpoint of the superior articular surface of the talus. Positive values indicated varus alignment, whereas negative values indicated valgus alignment (Fig. 3).

Reliability Analysis

All measurements were performed independently by two orthopedic surgeons in two separate sessions. Intra- and interobserver agreement was assessed using the intraclass correlation coefficient (ICC); ICC values ranged from 0.82 to 0.93 (Table 1).

Statistical Analysis

Continuous variables were expressed as mean±standard deviation (SD), and categorical variables as frequencies and percentages. The normality of continuous variables was assessed using the Shapiro–Wilk test. Between-group comparisons were performed using the independent-samples t-test for normally distributed continuous variables and the Mann–Whitney U test for non-normally distributed continuous variables. Categorical variables were compared using the chi-square test or Fisher's

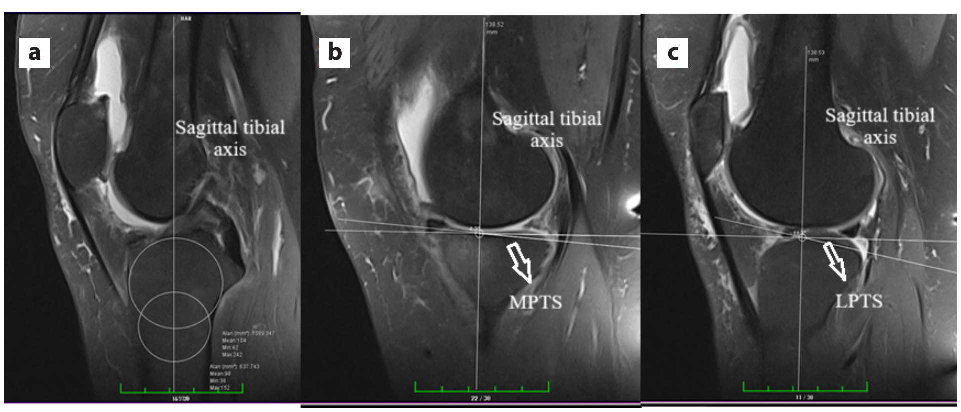

Figure 1. Measurement of posterior tibial slope on sagittal MRI. **(a)** The sagittal tibial longitudinal axis is established by drawing two circles tangent to the anterior and posterior tibial cortices on the sagittal MRI section in which the PCL tibial attachment, the intercondylar eminence, and the anterior and posterior tibial cortices are visible. The center of the caudal circle is placed at the border of the cranial circle, and the line connecting the two centers defines the tibial longitudinal axis. **(b)** Medial posterior tibial slope (MPTS) is measured as the angle between the tangent to the medial tibial plateau articular surface (arrow) and the perpendicular to the tibial longitudinal axis on the medial sagittal MRI section. **(c)** Lateral posterior tibial slope (LPTS) is measured using the same method on the lateral sagittal MRI section (arrow). Representative case: 59-year-old female with isolated degenerative MMPRT. MPTS: 4.3°, LPTS: 11.3°. *(MPTS: medial posterior tibial slope; LPTS: lateral posterior tibial slope; MRI: magnetic resonance imaging.)*

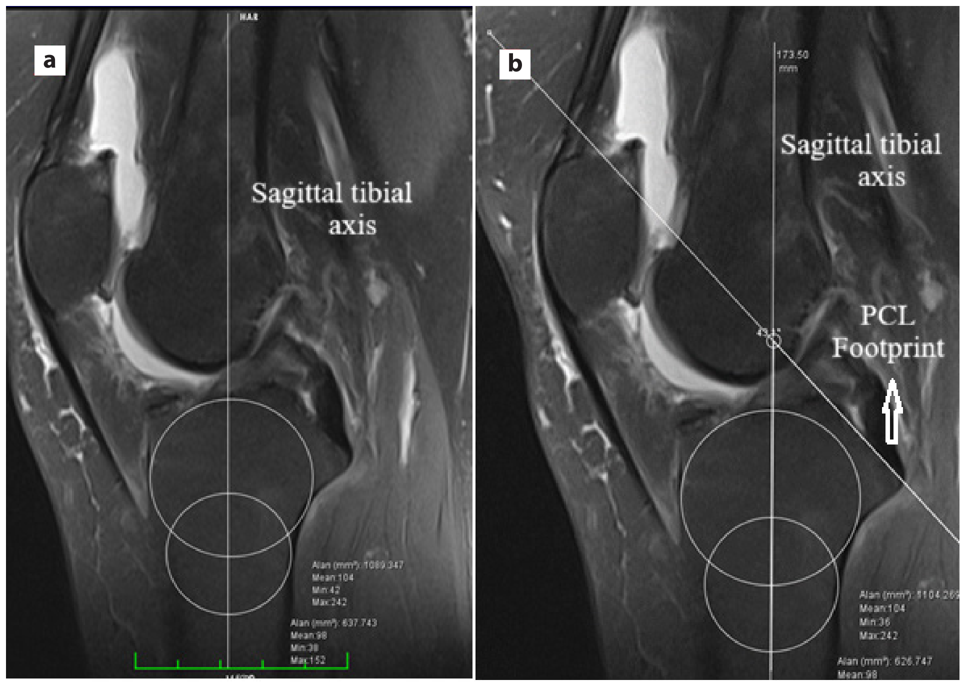

Figure 2. Measurement of the PCL tibial footprint angle (PCL-FPA) on sagittal MRI. **(a)** The sagittal tibial longitudinal axis is determined using the two-circle method on the sagittal MRI section where the PCL tibial attachment is best visualized. **(b)** A line is drawn parallel to the PCL tibial footprint (i.e., along the attachment surface of the PCL fibers on the tibia); PCL-FPA is then measured as the angle between this footprint line and the sagittal tibial longitudinal axis (arrow). Representative case: 59-year-old female with isolated degenerative MMPRT. PCL-FPA: 43.1°. *(PCL-FPA: PCL footprint angle; PCL: posterior cruciate ligament; MRI: magnetic resonance imaging.)*

exact test, as appropriate. Associations between radiological parameters and isolated degenerative MMPRT were evaluated using Firth-penalized logistic regression analysis. Each morphometric parameter was first assessed in a univariable model. Variables with a p-value<0.05 in the univariable analysis were subsequently entered into the multivariable Firth-penalized logistic regression model. Firth penalization was used to reduce small-sample bias and the potential effect of sparse data on maximum-likelihood estimates. Age and sex were balanced through the matching procedure and were therefore not included as covariates. Collinearity among the morphometric variables was assessed using pairwise correlations, and no evidence of problematic multicollinearity was identified. Regression results were reported as odds ratios (ORs) with 95% confidence intervals (CIs). Model performance was additionally summarized using McFadden's R^2 and the Akaike information criterion (AIC). The discriminative performance of the radiological parameters was assessed using receiver operating characteristic (ROC) curve analysis. Areas under the curve (AUCs) with 95% CIs were calculated, and optimal cutoff values were determined using the Youden index, with corresponding sensitivity and specificity values. The ROC curve for the combined model was generated from the predicted probabilities of the multivariable Firth-penalized logistic regression model. A two-sided p-value<0.05 was considered statistically significant. Statistical analyses were performed using R version 4.3.0 and SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Demographic Characteristics

A total of 192 patients were included, comprising 96 patients with isolated degenerative MMPRT and 96 age- and sex-matched controls. The mean age was 51.2±5.3 years in both groups, and 77 patients (80.2%) in each group were female. The distribution of the side of the evaluated knee was also similar between the groups (p=0.878) (Table 2).

Radiological Measurements

MPTS was similar between the MMPRT and control groups (9.56±2.76° vs. 9.22±2.73°, respectively; p=0.479). In contrast,

Figure 3. Measurement of varus alignment on a full-length weight-bearing radiograph. The mechanical axis varus angle is measured as the angle between two lines: the line drawn from the center of the femoral head to the center of the knee joint, and the line drawn from the center of the knee joint to the midpoint of the superior articular surface of the talus. Positive values indicate varus, and negative values indicate valgus alignment. Representative case: 59-year-old female with isolated degenerative MMPRT. Varus alignment: 5.2°.

Table 1. Intra- and inter-rater reliability of radiological measurements in the MMPRT and control groups

Radiological Parameter	Reliability Measure	MMPRT Group ICC	Control Group ICC
MPTS	Intra-rater, Observer 1	0.88	0.89
	Intra-rater, Observer 2	0.86	0.84
	Inter-rater	0.83	0.83
LPTS	Intra-rater, Observer 1	0.93	0.91
	Intra-rater, Observer 2	0.90	0.88
	Inter-rater	0.90	0.86
Varus alignment	Intra-rater, Observer 1	0.83	0.82
	Intra-rater, Observer 2	0.85	0.89
	Inter-rater	0.85	0.86
PCL-FPA	Intra-rater, Observer 1	0.92	0.93
	Intra-rater, Observer 2	0.88	0.85
	Inter-rater	0.87	0.87

MMPRT: medial meniscus posterior root tear; ICC: intraclass correlation coefficient.

LPTS was significantly greater in the MMPRT group than in the control group (10.94±3.25° vs. 7.51±3.03°; p<0.001). Varus alignment was also significantly greater in the MMPRT group (4.38±1.77° vs. 2.59±1.51°; p<0.001). PCL-FPA was significantly lower in the MMPRT group than in the control group (49.95±7.55° vs. 54.62±6.27°; p<0.001) (Table 3).

Firth-Penalized Logistic Regression Analysis

In the univariable Firth-penalized logistic regression analysis, MPTS was not significantly associated with isolated degenerative

Table 2. Demographic characteristics of the study groups

Parameter	Control (n=96)	Isolated MMPRT (n=96)	p
Age (years), mean±SD	51.2±5.3	51.2±5.3	1.000
Female, n (%)	77 (80.2)	77 (80.2)	1.000
Right knee, n (%)	47 (49.0)	46 (47.9)	0.878

SD: standard deviation; MMPRT: medial meniscus posterior root tear.

Table 3. Comparison of radiological measurements between the study groups

Parameter	Control (n=96)	Isolated MMPRT (n=96)	p
MPTS (°), mean±SD	9.22±2.73	9.56±2.76	0.479
LPTS (°), mean±SD	7.51±3.03	10.94±3.25	<0.001
Varus alignment (°), mean±SD	2.59±1.51	4.38±1.77	<0.001
PCL-FPA (°), mean±SD	54.62±6.27	49.95±7.55	<0.001

MPTS: medial posterior tibial slope; LPTS: lateral posterior tibial slope; PCL-FPA: posterior cruciate ligament footprint angle; SD: standard deviation.

Table 4. Univariable Firth-penalized logistic regression analysis

Variable	OR	95% CI	p
MPTS	1.047	0.944–1.162	0.384
LPTS	1.419	1.263–1.595	<0.001
Varus alignment	2.076	1.618–2.663	<0.001
PCL-FPA	0.907	0.867–0.949	<0.001

OR: odds ratio; CI: confidence interval; MPTS: medial posterior tibial slope; LPTS: lateral posterior tibial slope; PCL-FPA: posterior cruciate ligament footprint angle.

Table 5. Multivariable Firth-penalized logistic regression analysis

Variable	OR	95% CI	p
LPTS	1.497	1.283–1.746	<0.001
Varus alignment	2.199	1.656–2.922	<0.001
PCL-FPA	0.935	0.881–0.992	0.026

OR: odds ratio; CI: confidence interval; LPTS: lateral posterior tibial slope; PCL-FPA: posterior cruciate ligament footprint angle. McFadden R^2=0.395; AIC=169.0.

MMPRT (OR=1.047; 95% CI, 0.944–1.162; p=0.384). In contrast, greater LPTS (OR=1.419; 95% CI, 1.263–1.595; p<0.001), greater varus alignment (OR=2.076; 95% CI, 1.618–2.663; p<0.001), and lower PCL-FPA (OR=0.907; 95% CI, 0.867–0.949; p<0.001) were significantly associated with MMPRT (Table 4).

In the multivariable Firth-penalized logistic regression model, greater LPTS (OR=1.497; 95% CI, 1.283–1.746; p<0.001), greater varus alignment (OR=2.199; 95% CI, 1.656–2.922; p<0.001), and lower PCL-FPA (OR=0.935; 95% CI, 0.881–0.992; p=0.026) remained independently associated with isolated degenerative MMPRT. The model yielded a McFadden R^2 of 0.395 and an AIC of 169.0 (Table 5). Accordingly, each 1° increase in LPTS and varus alignment was associated with higher odds of MMPRT, whereas each 1° increase in PCL-FPA was associated with lower odds of MMPRT.

ROC Curve Analysis and Optimal Cutoff Values

Among the individual radiological parameters, varus alignment demonstrated the highest discriminative ability for isolated degenerative MMPRT, with an AUC of 0.790 (95% CI, 0.724–0.851). The optimal cutoff value for varus alignment was ≥3.2°, yielding a sensitivity of 71.9% and a specificity of 74.0%. LPTS demonstrated an AUC of 0.763 (95% CI, 0.693–0.824). The optimal cutoff value was ≥11.3°, with a sensitivity of 46.9% and a specificity of 91.7%. PCL-FPA demonstrated an AUC of 0.675 (95% CI, 0.598–0.745), with an optimal cutoff value of ≤50.1°, yielding a sensitivity of 53.1% and a specificity of 75.0%. MPTS demonstrated limited discriminative ability, with an AUC of 0.530 (95% CI, 0.502–0.612). The combined model incorporating varus alignment, LPTS, and PCL-FPA demonstrated greater discriminative performance than any individual parameter, with an AUC of 0.885 (95% CI, 0.835–0.929), a sensitivity of 75.0%, and a specificity of 86.5% (Table 6, Fig. 4).

DISCUSSION

In this matched case-control study, varus alignment, increased LPTS, and decreased PCL-FPA were independently associated with isolated degenerative MMPRT. Notably, PCL-FPA, a newly introduced morphometric parameter, demonstrated an independent association with MMPRT, suggesting that posterior tibial attachment geometry may represent an additional anatomical factor related to this condition. In contrast to previous reports emphasizing the role of MPTS, MPTS was not significantly associated with MMPRT in the present cohort, whereas LPTS remained independently associated in the multivariable model. These findings indicate that the morphometric profile of isolated degenerative MMPRT in an ACL-intact population may differ from that described in more heterogeneous cohorts. By excluding concomitant ACL pathology and using age- and sex-matched controls, the present study provides a more focused assessment of the relationship between tibial morphology and degenerative MMPRT.

The relationship between PTS and MMPRT is among the most frequently studied morphometric associations in the literature. Increased PTS has been biomechanically shown to increase compressive and anteriorly directed shear forces on the MMPR.[12] Systematic reviews have demonstrated associations between MMPRT and increased medial tibial slope, varus alignment, and reduced intercondylar dimensions.[6,7] In contrast, MPTS was similar between the groups in our study

Table 6. ROC analysis and optimal cutoff values for radiological parameters

Parameter	AUC	95% CI	Optimal cutoff	Sensitivity (%)	Specificity (%)
Varus alignment	0.790	0.724-0.851	≥3.2°	71.9	74.0
LPTS	0.763	0.693–0.824	≥11.3°	46.9	91.7
PCL-FPA	0.675	0.598–0.745	≤50.1°	53.1	75.0
Combined model	0.885	0.835–0.929	—	75.0	86.5

AUC: area under the receiver operating characteristic curve; CI: confidence interval; LPTS: lateral posterior tibial slope; PCL-FPA: posterior cruciate ligament footprint angle. Optimal cutoff values were determined using the Youden index.

and was not significantly associated with MMPRT (p=0.479). This finding may be related to differences in patient selection. A considerable proportion of the existing literature includes MMPRT cases with concomitant ACL pathology or uses patients with other meniscal tears as controls.[6] Differences in ACL status, control-group selection, and associated knee pathology may therefore contribute to the variability in reported associations between MPTS and MMPRT.

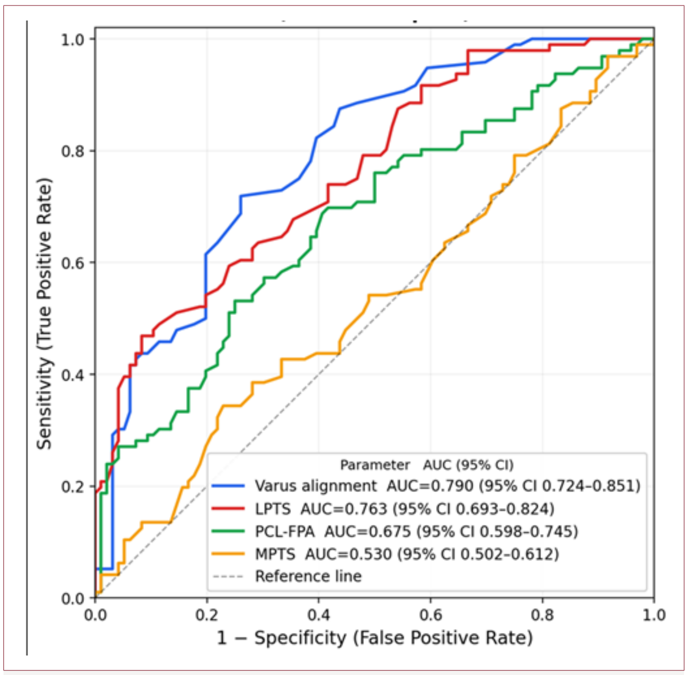

Figure 4. ROC curves for radiological parameters associated with isolated degenerative MMPRT (96 matched pairs). Varus alignment showed the highest individual AUC (0.790; 95% CI, 0.724–0.851), followed by LPTS (AUC=0.763; 95% CI, 0.693–0.824) and PCL-FPA (AUC=0.675; 95% CI, 0.598–0.745). MPTS demonstrated limited discriminative performance (AUC=0.530; 95% CI, 0.502–0.612). AUC: area under the curve; CI: confidence interval; LPTS: lateral posterior tibial slope; MPTS: medial posterior tibial slope; MMPRT: medial meniscus posterior root tear; PCL-FPA: posterior cruciate ligament footprint angle; ROC: receiver operating characteristic.

One notable finding of our study was that LPTS remained independently associated with MMPRT in the multivariable analysis (OR=1.497; p<0.001). The relationship between LPTS and MMPRT has not been systematically investigated in the literature. However, existing biomechanical evidence may provide a potential explanation for this association. Increased LPTS has been associated with greater anterior translation of the lateral tibial compartment and changes in tibial rotational kinematics.[7] Moreover, asymmetry between LPTS and MPTS has been reported to correlate with dynamic anterior tibial translation and may influence tibial displacement during loading.[13] These findings provide a possible biomechanical basis for the association observed between increased LPTS and MMPRT. A relatively steeper lateral slope may promote greater anterior translation of the lateral compartment and alter tibial rotational mechanics, potentially increasing loading of the medial compartment and posterior meniscus root. Confirmation of this association in larger cohorts and biomechanical studies is warranted. The recognized role of tibial slope in knee biomechanics has also prompted increasing interest in posterior tibial slope-modifying osteotomies, further emphasizing the potential clinical relevance of slope-related parameters.[14]

Varus alignment demonstrated the highest individual discriminative ability in our study (AUC=0.790) and remained independently associated with MMPRT in the multivariable analysis (OR=2.199; p<0.001). This finding is consistent with the existing literature. In a large series of 476 patients, the mean varus mechanical axis angle was significantly greater in patients with MMPRT than in controls (4.5°±3.4° vs. 2.4°±2.7°; p<0.01), closely corresponding to the values observed in our study (4.38° vs. 2.59°).[15] Varus alignment has also been consistently identified as a morphometric factor associated with MMPRT in systematic reviews.[7] The persistence of this association in an ACL-intact population further supports the importance of coronal alignment and medial compartment loading in degenerative MMPRT.

PCL-FPA is a novel radiological measurement parameter defined in this study and was independently associated with MMPRT in the multivariable analysis (OR=0.935; p=0.026). The weak correlations between PCL-FPA and MPTS and LPTS suggest that PCL-FPA may capture anatomical information that is largely distinct from tibial slope measurements. A potential anatomical basis for this association is the close proximity between the PCL tibial attachment and the medial meniscus posterior root. Cadaveric studies have demonstrated that the center of the medial meniscus posterior root lies only 8.2±0.7 mm from the nearest border of the PCL tibial attachment.[8] Given this close anatomical relationship, PCL-FPA may reflect not only the sagittal orientation of the PCL tibial attachment but also aspects of posterior tibial attachment geometry adjacent to the medial meniscus posterior root. Furthermore, given the role of the PCL in posterior tibial restraint and rotational stability, variation in PCL-FPA may also be related to biomechanical characteristics relevant to loading of the medial meniscus posterior root.[10]

From a biomechanical perspective, a decreased PCL-FPA represents a more horizontally oriented PCL tibial footprint. Because the medial meniscus posterior root occupies the same posterior tibial region, variations in footprint orientation may correspond to differences in the local attachment geometry of the posterior root. Such differences could potentially influence the distribution of tensile and shear forces across the root attachment during axial loading. However, this proposed mechanism remains hypothetical. PCL-FPA may therefore represent a distinct sagittal-plane morphometric characteristic of the posterior tibial attachment region rather than a direct measure of meniscal root biomechanics. The association between PCL-FPA and MMPRT should consequently be regarded as hypothesis-generating. Further anatomical and cadaveric biomechanical studies are required to determine whether PCL-FPA is directly related to medial meniscus posterior root attachment geometry or loading characteristics.

The combined model incorporating varus alignment, LPTS, and PCL-FPA demonstrated greater discriminative performance than any individual parameter, with an AUC of 0.885 compared with 0.790 for the best-performing individual parameter. This finding suggests that these variables may capture complementary morphometric characteristics associated with MMPRT. Varus alignment reflects coronal-plane medial compartment loading, LPTS may provide information related to tibial rotational biomechanics, and PCL-FPA may reflect posterior tibial attachment geometry in the sagittal plane. The ROC-derived cutoff values should be regarded as exploratory rather than clinically validated thresholds because they were derived from a single-center cohort and require external validation before clinical application. Nevertheless, the combined morphometric profile may help characterize knees with morphological features associated with degenerative MMPRT and may prompt closer evaluation of the posterior root on MRI.

A considerable proportion of previous studies have included patients with concomitant ACL pathology or have used patients with other meniscal pathologies as controls. ACL pathology is associated with altered tibiofemoral kinematics and meniscal loading and may therefore influence the observed relationships between tibial morphology and meniscal pathology.[16] Although obesity, female sex, advanced age, and varus alignment have been reported as factors associated with degenerative MMPRT,[17] evaluating morphometric parameters specifically in an isolated degenerative, ACL-intact population provides a more homogeneous assessment of these anatomical associations. The clinical importance of the medial meniscus posterior root is further supported by contemporary treatment strategies, including root repair combined with meniscal centralization in selected patients with meniscal extrusion.[18] The systematic exclusion of ACL pathology and the use of one-to-one age- and sex-matched controls constitute important strengths of the present study.

This study has several limitations. First, its retrospective, single-center design and relatively limited sample size may restrict the generalizability of the findings. Second, the control group comprised patients evaluated for nonspecific anterior knee pain rather than asymptomatic individuals. Although none had meniscal root pathology, this group may not fully represent a healthy population and may introduce selection bias. Third, although advanced osteoarthritis (Kellgren–Lawrence grade 3–4) was an exclusion criterion, individual KL grades were not systematically recorded because of the retrospective design. Therefore, residual differences in early osteoarthritic changes between the groups cannot be excluded and may have influenced parameters such as varus alignment and the observed associations. Fourth, BMI is a recognized factor associated with MMPRT; however, height and weight were not consistently available in the medical records, and BMI therefore could not be included in the regression analysis. Its potential confounding effect on the observed associations cannot be excluded. Fifth, PCL-FPA is a newly defined parameter whose biomechanical validity has not yet been established. In addition, the right-skewed distribution of LPTS values warrants caution when interpreting this parameter. The ROC-derived cutoff values should be considered exploratory and require external validation before clinical use. MMPRT was confirmed arthroscopically in some patients and diagnosed by MRI alone in others, which may have introduced diagnostic heterogeneity. Furthermore, medial meniscal extrusion, which is closely associated with MMPRT and medial compartment overload, was not systematically assessed. The combined model was not externally validated, and the cross-sectional case-control design, without longitudinal follow-up, precludes interpretation of the identified parameters as predictors of future MMPRT development. Prospective multicenter studies incorporating BMI, standardized osteoarthritis grading, and biomechanical validation of PCL-FPA are warranted.

CONCLUSION

Varus alignment, increased lateral posterior tibial slope, and decreased PCL footprint angle were independently associated with isolated degenerative medial meniscus posterior root tears. MPTS was not significantly associated with MMPRT in this ACL-intact cohort. Increased LPTS may reflect alterations in tibial rotational biomechanics associated with MMPRT, whereas PCL-FPA may represent a distinct morphometric characteristic of the posterior tibial attachment region. The combined assessment of mechanical alignment, LPTS, and PCL-FPA may improve characterization of the morphometric profile associated with isolated degenerative MMPRT. Because PCL-FPA is a newly defined parameter, its anatomical and biomechanical relevance requires further validation in prospective and biomechanical studies.

DECLARATIONS

Ethics Committee Approval: This study was approved by the Ethics committee of Necmettin Erbakan University Faculty of Medicine (27.02.2026 - 236).

Informed Consent: The requirement for informed consent was waived by the Ethics Committee due to the retrospective study design.

Conflict of Interest: The authors declared no conflict of interest.

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ABBREVIATIONS

ACL: Anterior cruciate ligament

AUC: Area under the curve

CI: Confidence interval

ICC: Intraclass correlation coefficient

LPTS: Lateral posterior tibial slope

MMPRT: Medial meniscus posterior root tear

MPTS: Medial posterior tibial slope

MRI: Magnetic resonance imaging

OR: Odds ratio

PCL: Posterior cruciate ligament

PCL-FPA: PCL footprint angle

ROC: Receiver operating characteristic

SD: Standard deviation

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