THE ATLANTIC Journal of Medical Science and Research

Atlantic J Med Sci Res 2026;6(3):271-7
DOI: 10.5455/atjmed.2026.03.021

Original Article

Associations of the hip–knee–ankle angle and joint line convergence angle with medial meniscal extrusion

Yusuf Polat, Abdullah Alper Sahin

Ordu University Training and Research Hospital, Department of Orthopaedics and Traumatology, Ordu, Türkiye

Received: 07 March, 2026
Accepted: 11 June, 2026
Published: 21 July, 2026

Corresponding Author: Yusuf Polat, Ordu University Training and Research Hospital, Department of Orthopaedics and Traumatology, Ordu, Türkiye
Email: dryusufpolat@gmail.com

CITATION
Polat Y, Sahin AA. Associations of the hip–knee–ankle angle and joint line convergence angle with medial meniscal extrusion. Atlantic J Med Sci Res. 2026;6(3):271-7. DOI: 10.5455/atjmed.2026.03.021

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Abstract

Aim: To examine the associations of the hip–knee–ankle angle (HKAA) and the joint line convergence angle (JLCA) with medial meniscal extrusion (MME). In addition, we aimed to determine their independent associations after adjusting for osteoarthritis severity and meniscal tear characteristics.

Materials and Methods: This single-center retrospective cross-sectional study included knees from patients aged ≥ 40 years with available full-length lower-limb radiographs and knee magnetic resonance imaging (MRI). Knees with HKAA ≥ -2° were included; varus alignment was recorded as positive and valgus alignment as negative. Radiographic alignment parameters, osteoarthritis severity, MME, and meniscal tear characteristics were recorded. Hierarchical multivariable regression was used to evaluate the independent associations of HKAA and JLCA with MME. Within-patient clustering was accounted for using generalized estimating equations.

Results: A total of 175 knees from 129 patients were analyzed. Mean HKAA was 4.66 ± 3.61°, mean JLCA was 2.09 ± 1.71°, and mean MME was 2.54 ± 1.96 mm. The covariate model explained 61.2% of the variance in MME (adjusted $R^2 = 0.599$). Adding HKAA increased the explained variance ($\Delta R^2 = 0.037$), and adding JLCA on top of HKAA provided modest additional explanatory value ($\Delta R^2 = 0.010$). In the fully adjusted generalized estimating equations (GEE) model, both HKAA (unstandardized coefficient, B = 0.077 mm/°; 95% CI 0.008 – 0.145; p = 0.028) and JLCA (B = 0.156 mm/°; 95% CI 0.008 – 0.305; p = 0.039) were independently and positively associated with MME.

Conclusion: MME is independently associated with coronal knee alignment. While HKAA appears to be the dominant alignment parameter, JLCA provides additional information beyond the mechanical axis. Clinical interpretation of MME should consider global mechanical alignment, JLCA, and posterior root integrity together.

Keywords: Medial meniscal extrusion, knee osteoarthritis, hip–knee–ankle angle, joint line convergence angle, coronal alignment

INTRODUCTION

The medial meniscus plays an important role in tibiofemoral load distribution, shock absorption, and knee stability. Meniscal roots and the organization of circumferential collagen fibers are essential for converting compressive loads into hoop stress. This mechanism limits meniscal extrusion during weight bearing, whereas its disruption is associated with meniscal extrusion and increased contact pressures (1). In addition to meniscal function, coronal alignment and deformity components that determine medial compartment loading should also be considered in the clinical evaluation (2).

Medial meniscal extrusion (MME), as an imaging marker of meniscal functional loss, and may be influenced by the coronal loading environment. Because varus alignment increases medial compartment load, it may also increase the tendency of the meniscus to displace outward (extrude). Accordingly, the relationship between MME and the hip–knee–ankle angle (HKAA), which reflects global lower-limb mechanical alignment, has been investigated in many studies (3-5). However, reliance on HKAA alone may be insufficient to characterize coronal-plane mechanics, because local joint-line factors such as intra-articular deformity and soft-tissue imbalance may create heterogeneous

DOI: 10.5455/atjmed.2026.03.021

medial-compartment loading even in knees with similar global lower-limb mechanical alignment. This local–global alignment mismatch supports the use of the joint line convergence angle (JLCA) as a complementary parameter that captures joint-line level convergence not fully represented by HKAA (6,7).

In this context, JLCA reflects coronal obliquity at the tibiofemoral joint line. Biomechanically, it represents the combined effects of intra-articular deformity and soft-tissue imbalance (6,8). JLCA has been reported to be associated with the severity of medial knee osteoarthritis, meniscal status, and cartilage degeneration (9). In addition, evidence suggests that an increase in JLCA, reflecting local varus tilt under load, may be associated with meniscal extrusion (10). However, few studies have examined whether JLCA provides additional explanatory value beyond HKAA for MME. Whether this incremental explanatory value remains after simultaneously accounting for osteoarthritis severity (K–L grade), posterior root tear status, and non-root meniscal tears remains unclear.

The aim of this study was to examine the associations of HKAA and JLCA with MME and to evaluate their independent associations after adjustment for osteoarthritis severity and meniscal tear characteristics. Accordingly, we investigated whether JLCA provides additional explanatory value beyond HKAA after controlling for K–L grade, posterior root tears, and non-root meniscal tears.

MATERIALS AND METHODS

Study Design and Ethical Approval

This was a single-center, retrospective cross-sectional study conducted using data retrieved from the hospital Picture Archiving and Communication System (PACS) between January 2025 and January 2026. During this period, cases with full-length lower-limb radiographs and corresponding knee magnetic resonance imaging (MRI) examinations were consecutively screened in PACS, and all cases meeting the inclusion/exclusion criteria were included. For patients meeting eligibility criteria bilaterally, both knees were included in the analysis; within-patient clustering was accounted for in the statistical analyses. The study protocol was approved by the Ordu University Non-Interventional Clinical Research Ethics Committee (Approval date: 27 February 2026; Approval No.: 2026/55).

Inclusion criteria were: (i) age ≥ 40 years; (ii) availability of both a full-length lower-limb radiograph and a knee MRI for the same knee; and (iii) HKAA ≥ -2°, with varus alignment recorded as positive and valgus alignment as negative. Exclusion criteria were radiographic and/or MRI evidence of prior major surgery on the ipsilateral or contralateral lower extremity, such as implants/fixation hardware, post-osteotomy changes, arthroplasty components, or marked post-traumatic deformity/malunion. Knees with ligament rupture or clear ligament insufficiency on MRI, or findings suggestive of tumor or osteonecrosis, were also excluded. Additional exclusion criteria were an interval > 6 months between the full-length radiograph and knee MRI for the same knee, inadequate image quality for measurement, or significant imaging artifact.

Radiographic Assessment

Full-length lower-limb radiographs were obtained under standardized weight-bearing conditions Coronal alignment parameters, including HKAA and the JLCA, were measured. Knee MRI examinations were evaluated primarily on coronal proton density fat-suppressed (PD-FS) images, with standard sagittal and axial sequences reviewed as needed.

HKAA (°) was measured as the angle between the femoral mechanical axis, defined as the line connecting the center of the femoral head and the center of the knee joint, and the tibial mechanical axis, defined as the line connecting the center of the knee joint and the center of the talus. Varus was recorded as positive and valgus as negative. JLCA (°) was measured as the convergence angle between the joint line of the femoral condyles and the joint line of the tibial plateau. Osteoarthritis severity was graded on weight-bearing anteroposterior knee radiographs using the Kellgren–Lawrence (K–L) scale (grades 0–4) (11). For analysis, K–L grades 0–2 were grouped together, whereas grades 3–4 were classified as advanced osteoarthritis.

Meniscal pathology on MRI was recorded using two variables: (i) presence or absence of a posterior root tear and (ii) non-root meniscal tear category (none, degenerative/complex, other). The ‘other’ category included non-root meniscal tears other than degenerative/complex tears (e.g., horizontal, radial, flap, or longitudinal tears). MME was measured on coronal images at the mid-body of the medial meniscus (the slice showing maximum extrusion) as the shortest distance, in millimeters, between the most peripheral edge of the meniscus and the medial cortical margin of the tibial plateau. When osteophytes were present, measurements were referenced to the true cortical margin of the tibial plateau rather than the osteophyte tip, thereby standardizing MME measurements by excluding osteophytes from the reference margin. For descriptive group comparisons, MME was categorized using a 3-mm cutoff as ≤ 3 mm and > 3 mm. An illustrative example is shown in Figure 1.

Observer reliability of the measurements was assessed by two independent raters in a randomly selected 20% of knees. For inter-rater reliability, both raters measured the same images independently; for intra-rater reliability, measurements were repeated after 1 week. Intraclass correlation coefficients (ICCs) for MME, HKAA, and JLCA were reported with 95% confidence intervals (inter-rater: two-way random, absolute agreement, single measures; intra-rater: two-way mixed, absolute agreement, single measures). All intra- and inter-rater ICC values exceeded 0.90, indicating excellent measurement reliability.

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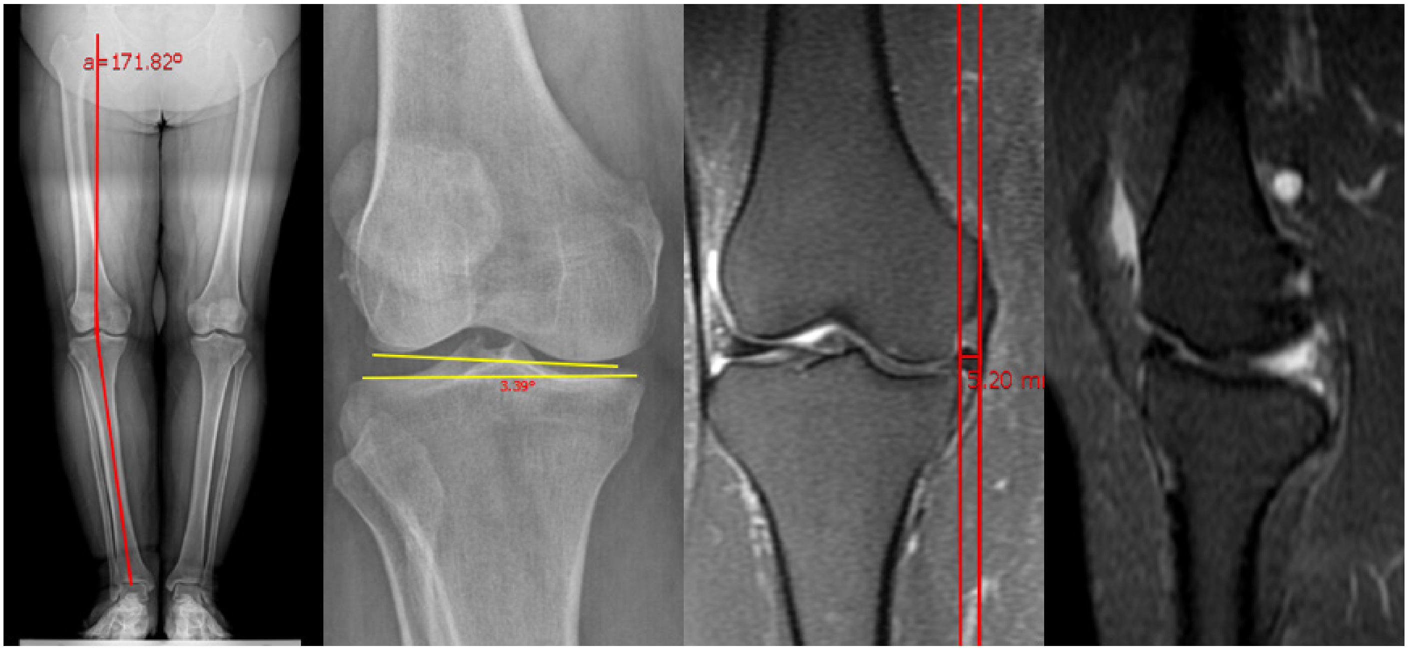

Figure 1. Representative case demonstrating the measurement of HKAA and JLCA on a weight-bearing full-length radiograph and medial meniscal extrusion on coronal MRI

Statistical analysis

Continuous variables were presented as the mean ± standard deviation (SD) when normally distributed and as the median (interquartile range [IQR]) when non-normally distributed. Categorical variables were presented as n (%). Normality was assessed using the Shapiro–Wilk test together with visual inspection of Q–Q plots, considering the sample-size sensitivity of the test. Between-group comparisons (MME ≤ 3 mm vs > 3 mm) were performed using the independent-samples t-test or Mann–Whitney U test for continuous variables, and the chi-square test or Fisher's exact test for categorical variables. For the dependent variable MME (mm), hierarchical (blockwise) ordinary least squares (OLS) regression was performed: age, sex, side, K–L group, and meniscal tear characteristics were entered as covariates, with HKAA and JLCA added in subsequent blocks to assess incremental explained variance (ΔR^2). Multicollinearity was assessed using the variance inflation factor (VIF) and was minimal (all VIFs < 2.0). Because some patients contributed both knees, standard errors were adjusted for patient-level clustering using cluster-robust (Huber–White) standard errors. As a sensitivity analysis, a generalized estimating equations (GEE) model was also fitted using a Gaussian distribution, identity link, exchangeable correlation structure, and robust standard errors. Regression coefficients were reported as unstandardized coefficients (B) with 95% confidence intervals. A two-sided $p < 0.05$ was considered statistically significant. Analyses were performed using IBM SPSS Statistics for Windows, Version 20.0 (IBM Corp., Armonk, NY, USA).

RESULTS

In this retrospective study, a total of 175 knees from 129 patients were evaluated; the cohort comprised 30 men (23.2%) and 99 women (76.8%), with a mean age of 50.37 ± 6.63 years (range, 40–70). Of the knees, 82 were right (46.9%) and 93 were left (53.1%). According to the K–L grouping, 61.7% (n = 108) of knees were classified as K–L 0–2 and 38.3% (n = 67) as K–L 3–4. Posterior root tears were identified in 30.3% (n = 53). The distribution of non-root meniscal tears was 57.7% "none," 25.7% "degenerative/complex," and 16.6% "other".

Using a 3 mm threshold, knees were grouped as MME ≤ 3 mm (n = 111) and MME > 3 mm (n = 64). The MME > 3 mm group was older ($p = 0.002$) and had a higher proportion of right knees ($p = 0.027$), while sex distribution did not differ between groups ($p = 0.470$). Advanced osteoarthritis (K–L 3–4) and posterior root tears were markedly more frequent in the MME > 3 mm group (both $p < 0.001$). HKAA and JLCA values were also higher in the MME > 3 mm group (both $p < 0.001$) (Table 1).

In the hierarchical linear regression analysis, the covariate model (age, sex, side, K–L group, posterior root tear, and non-root meniscal tears) explained $R^2 = 0.612$ of the variance (adjusted $R^2 = 0.599$). Adding HKAA increased the explained variance ($\Delta R^2 = 0.037$), and adding JLCA after HKAA further increased the explained variance ($\Delta R^2 = 0.010$). In a separate model, adding JLCA to the covariate model without HKAA also increased the explained variance ($\Delta R^2 = 0.031$) (Table 2).

In a patient-clustered GEE model with robust standard errors, MME was independently associated with side, K–L group,

DOI: 10.5455/atjmed.2026.03.021

posterior root tear, and non-root meniscal tears. In the fully adjusted model, both HKAA (B = 0.077; 95% CI 0.008 – 0.145; p = 0.028) and JLCA (B = 0.156; 95% CI 0.008 – 0.305; p = 0.039) were independently and positively associated with MME, whereas age and sex were not significant. Reference categories are shown in Table 3.

Table 1. Comparison of demographic, radiographic, and MRI findings between knees with medial meniscus extrusion ≤ 3 mm and > 3 mm

Variables	Extrusion ≤ 3 mm (n = 111)	Extrusion > 3 mm (n = 64)	Statistics	p value
Age (mean ± SD)	49.21 ± 6.88	52.38 ± 5.68	t = -3.12	0.002[a]
Sex, n (%)			χ^2 = 0.52	0.470[b]
Male	26 (23.4)	12 (18.8)		
Female	85 (76.6)	52 (81.2)		
Side, n (%)			χ^2 = 4.86	0.027[b]
Left	66 (59.5)	27 (42.2)		
Right	45 (40.5)	37 (57.8)		
K–L group, n (%)			χ^2 = 43.80	< 0.001[b]
0–2	89 (80.2)	19 (29.7)		
3–4	22 (19.8)	45 (70.3)		
Posterior root tear, n (%)			χ^2 = 54.52	< 0.001[b]
No	99 (89.2)	23 (35.9)		
Yes	12 (10.8)	41 (64.1)		
Non-root meniscal tears, n (%)			χ^2 = 17.36	< 0.001[b]
None	60 (54.1)	41 (64.1)		
Degenerative/complex	23 (20.7)	19 (30.5)		
Other	28 (25.2)	4 (6.4)		
HKAA (°) (mean ± SD)	3.47 ± 2.97	6.58 ± 3.36	t = -6.36	< 0.001[a]
JLCA (°) (mean ± SD)	1.63 ± 1.50	3.36 ± 1.75	t = -6.95	< 0.001[a]

Data are presented as mean ± SD or n (%); [a] independent-samples t-test; [b] Pearson's chi-square test or Fisher–Freeman–Halton exact test where appropriate; Statistical significance was set at $p < 0.05$

Table 2. Hierarchical linear regression models for medial meniscus extrusion (OLS)

Model	Predictors	R^2	Adjusted R^2	ΔR^2
0	Covariate model	0.612	0.599	—
1	Model 0 + HKAA	0.650	0.635	0.037
2	Model 1 + JLCA	0.660	0.644	0.010
3*	Model 0 + JLCA	0.644	0.629	0.031

Dependent variable: medial meniscus extrusion (mm); Covariates: age, sex, side, K–L group (0–2 vs 3–4), posterior root tear, non-root meniscal tear category; ΔR^2 reflects the incremental contribution at each step; *Model 3 was fitted as a separate model by adding JLCA to the covariate model

Table 3. Factors associated with medial meniscus extrusion (GEE with robust SE)

Predictor	B	Robust SE	95% CI	p value
Intercept	**4.081**	1.096	1.934 – 6.229	< 0.001
Age	**0.008**	0.015	-0.022 – 0.037	0.622
Sex (male vs female)	**-0.347**	0.229	-0.795 – 0.101	0.129
Side (right vs left)	**0.361**	0.127	0.112 – 0.611	0.004
K–L group (0–2 vs 3–4)	**-0.840**	0.244	-1.319 – -0.362	0.001
Posterior root tear (no vs yes)	**-2.697**	0.240	-3.168 – -2.226	< 0.001
Non-root meniscal tears (none vs other)	**-0.952**	0.179	-1.304 – -0.601	< 0.001
Non-root meniscal tears (degenerative/complex vs other)	**0.871**	0.273	0.335 – 1.406	0.001
HKAA (°)	**0.077**	0.035	0.008 – 0.145	0.028
JLCA (°)	**0.156**	0.076	0.008 – 0.305	0.039

Dependent variable: medial meniscus extrusion (mm); Coefficients are from a GEE model with robust (sandwich) standard errors accounting for within-patient clustering; B represents the unstandardized regression coefficient, indicating the change in extrusion (mm) per 1-unit increase in continuous predictors (1 year for age; 1° for HKAA/JLCA) or relative to the reference category for categorical predictors; GEE: generalized estimating equations, SE: standard error

DISCUSSION

The main finding of this study is that MME is independently associated not only with HKAA, which represents global coronal alignment, but also with JLCA, which more closely reflects intra-articular deformity and soft-tissue imbalance. After adjustment for osteoarthritis severity (K–L), meniscal pathology (posterior root tears and non-root meniscal tears), and key demographic variables, HKAA accounted for a larger share of the explained variance in MME, whereas JLCA provided modest but incremental additional explanatory value beyond HKAA. These results suggest that the mechanical factors associated with MME may not be fully captured by a single alignment metric, and that considering global axis deviation together with joint-line level convergence may enable more accurate mechanical phenotyping.

The persistence of JLCA as an independent correlate may be particularly valuable in cases with similar overall alignment, where HKAA does not adequately capture intra-articular variation, such as within-compartment asymmetry, compression, or soft-tissue imbalance. JLCA has been reported as one of the alignment-related factors closely associated with the severity of medial knee osteoarthritis (9). Under weight-bearing conditions, increased JLCA, reflecting local varus joint-line tilt, correlates with MME, suggesting that weight-bearing JLCA may reflect load-related meniscal displacement (12). Moreover, finite element analyses have shown that an increase in JLCA, together with MME, can elevate medial compartment stresses (10). Within this framework, HKAA can be viewed as a global lower-limb alignment parameter, whereas JLCA may serve as a complementary joint-line parameter reflecting compartmental load asymmetry related to intra-articular deformity and soft-tissue imbalance.

The positive association between varus alignment and MME is consistent with the literature. In a large MRI-based cohort, varus malalignment was independently associated with MME, even after adjustment for meniscal and cartilage pathology (13). Clinical data showing that MME increases with HKAA even in varus knees without a meniscal tear support this mechanism. In this context, varus alignment may increase medial compartment loading and thereby promote outward displacement of the meniscus beyond the tibial margin (3,5). Biomechanical studies have also shown that varus alignment increases both MME and medial compartment contact pressures (4,14). In addition, longitudinal data indicate that MME should not be interpreted merely as an isolated degenerative finding. When accompanied by meniscal damage, malalignment, and joint laxity, MME may reflect a mechanically adverse joint environment associated with subsequent cartilage loss (7,15,16).

An ancillary finding was the independent association between side and MME, with right knees showing greater extrusion than left knees. This side-related difference may reflect unmeasured limb dominance, asymmetric limb loading, or habitual activity-related mechanical factors; however, because these factors were not specifically assessed, the finding should be interpreted cautiously.

The higher frequency of posterior root tears in the > 3 mm MME group suggests that extrusion may reflect impaired meniscal load transmission, rather than being solely a consequence of degenerative loading, with loss of hoop-stress function likely contributing to this process. Allaire et al. demonstrated that posterior medial meniscal root tears markedly increase tibiofemoral contact pressure and may have biomechanical

DOI: 10.5455/atjmed.2026.03.021

effects comparable to those of a total meniscectomy (17). Therefore, in knees with compromised posterior root integrity, an increase in MME would be expected in parallel with the varus-related increase in medial compartment loading.

A recent study in osteoarthritic knees reported comparable MME values in medial meniscus posterior root tears and radial tears with complex tear components, with both tear types independently predicting MME > 3 mm (18). MRI-based evidence also suggest that MME may be closely associated not only with posterior root lesions but also with advanced meniscal degeneration and complex tears. Costa et al. reported that MME greater than 3 mm was associated with severe meniscal degeneration, complex tears, and radial tears. Additional MRI-based studies have linked posterior root pathology and radial tears to extrusion in degenerative joint disease (19,20). Within this framework, even in cases without an identified posterior root tear, certain non-root meniscal tear subtypes—particularly those with complex/degenerative features—may still be associated with extrusion. In our series, the significant difference in non-root meniscal tear distribution between the ≤ 3 mm and > 3 mm MME groups further supports this association.

Regarding threshold selection, although a 3-mm cutoff is commonly used in practice, MME is a continuous variable and its clinical meaning is context-dependent rather than defined by a single threshold. A recent review emphasized that while 3 mm is often used as a classic pathologic threshold, values <3 mm do not exclude meniscal injury; alternative cutoffs such as 2.5 mm and 4 mm have also been reported, and therefore, 3 mm threshold should be viewed primarily as a screening threshold on standard coronal MRI (21). Liu et al. reported, using Osteoarthritis Initiative data, that an MME threshold of approximately 2.5 mm may be useful for predicting worsening pain and progression of cartilage damage (22). Therefore, reporting MME as a continuous variable in the primary analyses—and positioning threshold-based classifications as secondary or sensitivity analyses—represents a more robust reporting approach.

The limitations of this study include the inability to infer causality due to the retrospective cross-sectional design, the use of supine MRI for MME measurement, and the omission of potential confounders such as body mass index (BMI) and dynamic laxity or varus thrust from the models. Nevertheless, the combined evaluation of HKAA and JLCA on full-length radiographs, together with adjustment for osteoarthritis severity and meniscal tear characteristics, strengthens the clinical relevance of our findings in terms of mechanical phenotyping. Future prospective follow-up studies testing the predictive value of the combined HKAA–JLCA profile for changes in MME and structural progression may clarify how these relationships translate into clinical outcomes.

CONCLUSION

This study demonstrates that MME is significantly and independently associated with coronal knee alignment. While HKAA appears to be the dominant alignment parameter, JLCA provides additional, independent information beyond the mechanical axis. Clinically, interpretation of MME should therefore consider not only the mechanical axis but also JLCA—which reflects deformity at the joint-line level—together with the integrity of the posterior meniscal root. Future studies using weight-bearing imaging and prospective follow-up are needed to confirm how these relationships translate into clinical outcomes.

Conflict of Interests
The authors declare that there is no conflict of interest in the study.

Financial Disclosure
The authors declare that there is no financial support.

Ethical Approval
The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ordu University Non-interventional Clinical Research Ethics Committee (Date: 27.02.2026, Approval No: 2026/55).

Informed Consent
The requirement for informed consent was waived by the ethics committee because this retrospective study used previously obtained anonymized radiographic and MRI data.

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