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Steeper tibial and meniscal slopes as predictive factors for ramp lesions in anterior cruciate ligament injuries

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The relationship between ramp lesion (RL), tibial slope (TS), and meniscal slope (MS) remains inadequately explored. This study aims to investigate whether TS and MS are predictive factors for anterior cruciate ligament (ACL) injuries associated with RL, and to evaluate the performance of TS and MS in predicting RL, including determining optimal cut-off values. A retrospective cohort study was conducted on 253 patients who underwent ACL reconstruction. Magnetic resonance imaging was used to measure TS and MS on tibial plateaus. Logistic regression analyses determined associations between TS, MS, and RL. Receiver operating characteristic (ROC) curves evaluated predictive performance and cut-off values. A total of 65 cases (25.7%) were found to have RL. Significant differences in causes of injury, medial TS (MTS), medial MS (MMS), and bone bruises were observed between groups. In the unadjusted model and adjusted models, they showed significant ($P<0.001$) associations for MTS (1.73–1.75) and MMS (OR range = 2.14–2.24). The AUC for MTS was 0.72 (95% CI 0.65–0.79, $P<0.001$) with a cut-off value of 6.73°, for MMS was 0.80 (95% CI 0.74–0.86, $P<0.001$) with a cut-off value of 4.03°, indicating good predictive performance. Larger MTS and MMS are significant predictive factors for RL in patients with ACL injury. Clinicians should closely monitor ACL injury patients with elevated MTS or MMS. Utilizing MTS or MMS as a predictive parameter shows promise for the identification of RL.

Keywords Magnetic resonance imaging, Knee joint, Cohort studies, Diagnostic techniques and procedures

The anterior cruciate ligament (ACL) is crucial for maintaining knee stability by primarily limiting tibial anterior displacement and rotation[1]. The incidence of ACL tears among individuals aged 16–39 years is 85 per 100,000, with approximately 200,000 cases occurring annually in the United States[2], often resulting from non-contact mechanisms, which are more prevalent than high-energy contact injuries[3]. Such injuries not only compromise knee stability but also predispose patients to secondary damage of the menisci and articular cartilage, accelerating joint degeneration[4].

The meniscus serves as a primary stabilizer for distributing axial loads in the knee joint and crucial in its function. Post-ACL injury, increased tibial translation and rotational forces elevate the stress on the menisci, heightening the risk of meniscal tears. Ramp lesions (RL), defined as longitudinal vertical or oblique peripheral tears, less than 2 cm in a mediolateral direction, in the posterior horn of the medial meniscus[5], occur in approximately 16-34.5% of ACL-injured knees[6–9]. These lesions can compromise knee stability and contribute to pain and degenerative changes, highlighting the importance of early detection and appropriate management.

Knee joint morphology may influence the development of RL. Steeper tibial slope (TS) and meniscal slope (MS) increase shear forces within the knee, potentially exacerbating meniscal stress and tear susceptibility. However, there is mixed evidence regarding the role of MTS and MMS as predictive factors for RL[8,10]. While some research support MMS[11] or MTS[12] as predictive factors, others report no association[9,13] or identify only one of these parameters[11,12]. Moreover, many studies have employed single-factor analyses with limited multivariable adjustments[8,9,11–13], which may potentially overlook confounding variables reducing the robustness of their conclusions.

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This study aims to elucidate the relationship between TS, MS, and the occurrence of RL in ACL injured patients using multivariable regression models. We hypothesize that patients with larger TS and MS are at higher likelihood of developing RL following ACL injury.

Methods

This study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology checklist[14]. This retrospective cohort study included 253 patients who underwent ACL reconstruction at Affiliated Hospital of Shandong University of Traditional Chinese Medicine between October 2019 to December 2023. (Fig. 1).

Inclusion criteria:

- Adults aged ≥ 18 years.
- Underwent ACL reconstruction surgery.
- Available preoperative knee sagittal magnetic resonance imaging (MRI) slices.

Exclusion criteria:

- Severe osteoarthritis (≥ Kellgren-Lawrence 3 grade) or arthritis.
- Varus or valgus deformity.
- History of previous knee surgery on the affected limb.
- Combined surgical procedures operation (i.e., internal fixation or osteotomy).

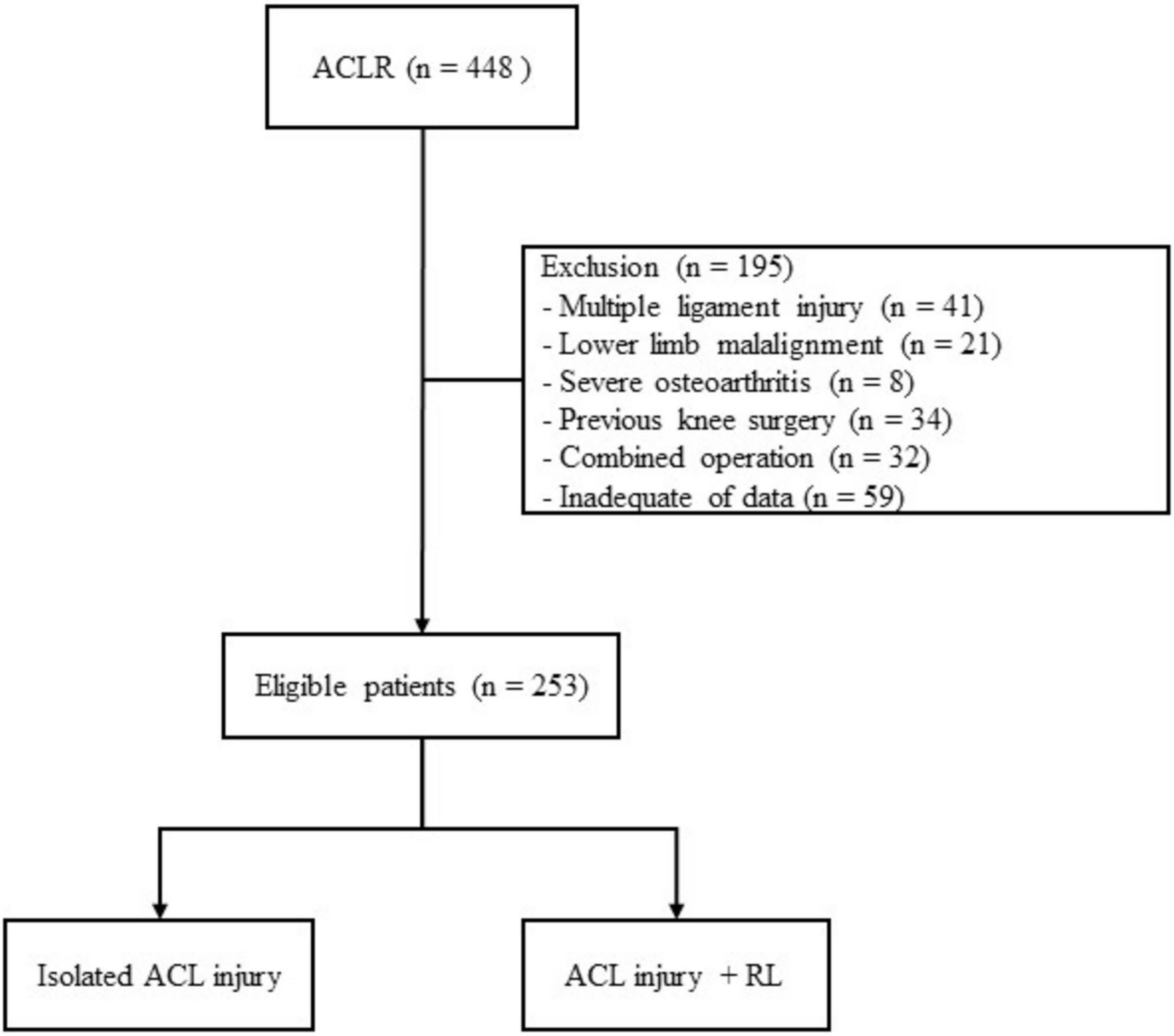

Fig. 1. Illustrates the selection process of participants, starting from the initial assessment, exclusion criteria, and final analysis.

This study adheres to the Declaration of Helsinki and has been approved by the Medical Ethics Committee of Affiliated Hospital of Shandong University of Traditional Chinese Medicine, ethical approval number: (2023) Lunshen No. (136) - KY. Informed consent was obtained and the rights of subjects were protected.

Preoperative data collection

The sex, age, body mass index (BMI), injury side, time from injury, and cause of ACL injury for all patients were collected from the electronic medical record system.

Surgical procedures

All ACL reconstruction procedures used the same protocol. Standard anteromedial and anterolateral portals were made for ACL reconstruction surgery. Systematic arthroscopic evaluation was performed with 30°and 70° arthroscopes before the ACL reconstruction. In addition to a systematic assessment of the knee joint cavity, the posteromedial compartment was evaluated using a notch view. A dural puncture needle was also inserted posteriorly and medially to examine the integrity of the joint capsule transition zone, with tibial internal rotation employed to optimize visualization. If integrity was compromised, a posteromedial portal was established, and an arthroscopic probe was introduced to further assess the type and extent of the RL, followed by suturing[10] (Fig. 2).

Measurement of TS and MS

Demographic information was extracted from the patients' medical histories. Preoperative MRI scans (Philips Ingenia 3.0T) were conducted with patients in a relaxed, fully extended knee position. TS and MS measurements were performed using the Picture Archiving and Communication System (PACS) software by X. W. and K. L. both blinded to the patients' clinical data.

Following Hudek et al.[15] and Wang et al.[16], TS was measured on sagittal T1-weighted images. The central sagittal slice was selected to clearly visualize the posterior cruciate ligament and intercondylar eminence. The proximal anatomical axis was defined by drawing two circles in the proximal tibia: a proximal circle tangent to the proximal, anterior, and posterior cortices, and a distal circle centered at the perimeter of the proximal circle. The line connecting the centers of these circles defined the proximal anatomical axis (Fig. 3). The slope for the medial and lateral compartments were measured on the central slices of the medial and lateral compartments, respectively. The central slice was defined as the middle slice between the inner or outer edge of the tibial platform and the intercondylar ridge. The proximal anatomical axis was translated to these two slices. Medial TS was measured by drawing a line tangent to the anterior and posterior edges of the medial tibial plateau and another line perpendicular to the proximal anatomical axis. The angle between the two lines represented the medial TS. Additionally, a tangent line to the anterior and posterior horns of the meniscus was drawn, and the angle between this line and line perpendicular to the proximal anatomical axis was recorded as the medial MS. The same method was used for lateral MS and TS (Fig. 4).

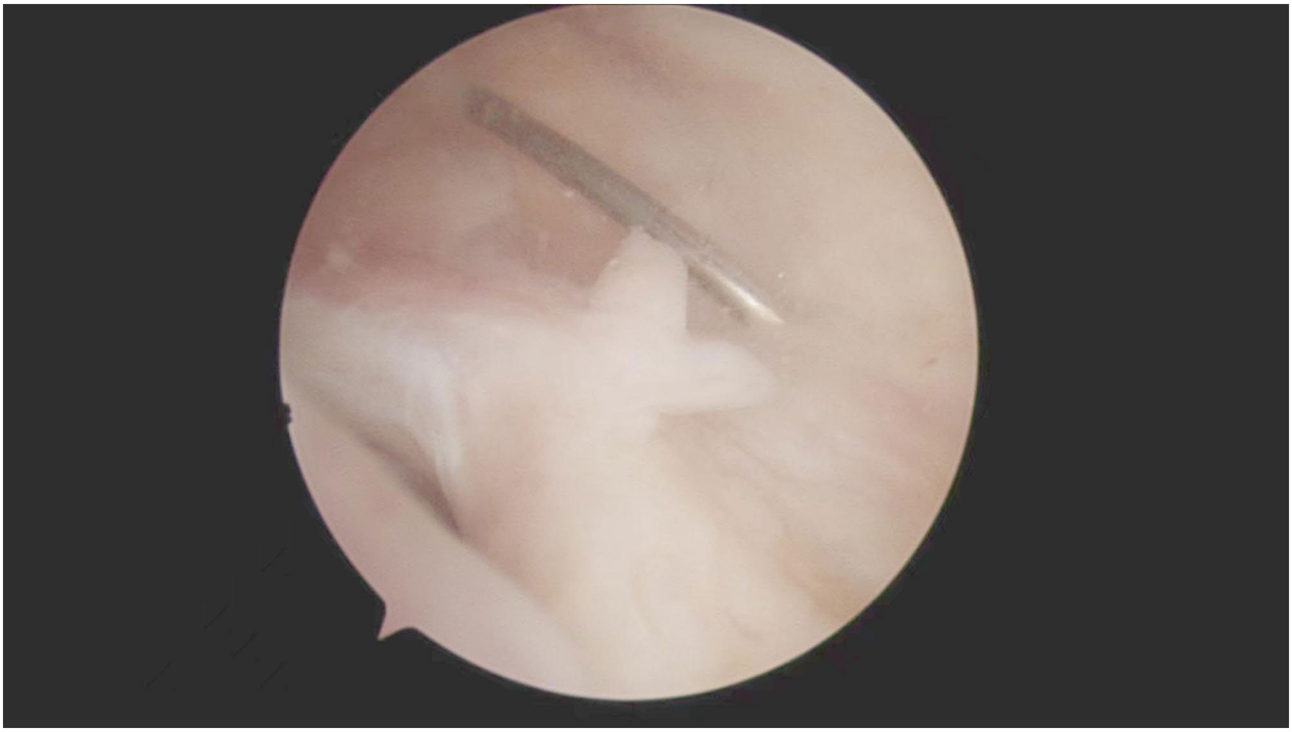

Fig. 2. Illustration of ramp lesion.

Fig. 3. Illustration of proximal anatomical axis. *denotes posterior cruciate ligament.

Statistics

All statistical analyses were conducted using SPSS 26.0 (IBM Corp. Armonk, USA). Continuous data with normal distribution were described as mean ± standard deviation (SD) and Student's t-test used for analysis. Continuous data without normal distribution were described as mean (IQR) and Mann-Whitney U test used for analysis. Normal Shapiro-Wilk test was used normality of the distribution. Categorical data were expressed as frequencies and percentages. Chi-square tests or Fisher's exact probability method were used for analysis. Multivariable logistic regression was used to model the relationship between the presence or absence of ramp lesion (as the dependent variable) and MTS or MMS (as the independent variables). The results of the logistic regression are presented as odds ratios (ORs) with 95% confidence intervals (CIs), which describe the magnitude and direction of the association between MTS/MMS and the likelihood of having or not having a ramp lesion.

Model 1: unadjusted.

Model 2: adjusted for, BMI, injury side, time from injury, cause of injury and bone bruise.

Model 3, variables showed significantly difference between patients with RL and without RL were adjusted.

In this study, the Receiver Operating Characteristic (ROC) curve was used to identify the optimal cut-off points for predicting the risk of ramp lesion. The ROC curve was plotted by varying the threshold for classification, with the true positive rate (sensitivity) on the y-axis and the false positive rate (1-specificity) on

Fig. 4. The measurements of tibial slope and meniscal slope. (**A**) Lateral tibial slope (LTS): the angle between the lateral tibial slope and the line perpendicular to the proximal anatomical axis. (**B**) Lateral meniscal slope (LMS): the angle between the lateral meniscal slope and the line perpendicular to the proximal anatomical axis. (**C**) Medial tibial slope (MTS): the angle between the medial tibia slope and the line perpendicular to the proximal anatomical axis. (**D**) Medial meniscal slope (MMS): the angle between the medial meniscal slope and the line perpendicular to the proximal anatomical axis.

the x-axis. The optimal cut-off point was determined by selecting the threshold that maximized the sum of sensitivity and specificity, or alternatively, by choosing the point closest to the top-left corner of the ROC curve, which represents the best trade-off between sensitivity and specificity.

Area Under the Curve (AUC), which quantifies the overall performance of the parameter in distinguishing between positive and negative cases. An AUC of 0.5 indicates no better performance than random chance, while an AUC closer to 1.0 suggests excellent discrimination ability. In this context, a higher AUC value indicates a stronger predictive ability in correctly identifying individuals with and without ramp lesion.

An alpha level was set at $P < 0.05$. The Bonferroni correction was applied to control for the multiple comparisons problem and reduce the risk of Type I errors. Specifically, the significance level (alpha) was divided by the number of tests conducted, adjusting the p-value threshold for each individual hypothesis. For instance,

Characteristic	Ramp lesion		P value
	Yes (N = 65)	No (N = 188)	
Sex			0.109
Male	52(80.0%)	131(69.7%)	
Female	13(20.0%)	57(30.3%)	
Age, years	32.00(12)	31.00(12)	0.379
BMI, kg/m^2	24.06 ± 3.38	23.33 ± 3.09	0.11
Injury side			0.084
Left	35(53.9%)	78(41.5%)	
Right	30(46.2%)	110(58.5%)	
Time from injury			
< 3ms	29(44.6%)	96(51.1%)	
3-6ms	15(23.1%)	41(21.8%)	
> 6ms	21(32.3%)	51(27.1%)	
Cause of injury			0.021
Contact injury	24(36.9%)	36(19.2%)	
Noncontact injury	41(63.1%)	152(80.9%)	
MMS, °	5.04(1.81)	3.45(1.69)	< 0.001
MTS, °	7.41 ± 1.54	6.15 ± 1.49	< 0.001
LMS, °	4.22 ± 1.71	4.45 ± 1.49	0.308
LTS, °	6.88(2.43)	6.35(2.08)	0.113
Bone bruise			0.012
Yes	13(20.0%)	16(8.5%)	
No	52(80.0%)	172(91.5%)	

Table 1. Characteristics of included patients. BMI, body mass index; MMS, medial meniscal slope; MTS, medial tibial slope; LMS, lateral meniscal slope; LTS, lateral tibial slope.

Variable	Model	β	OR	95% CI	P
MMS	Model 1	0.81	2.24	1.75–2.88	< 0.001
	Model 2	0.76	2.14	1.66–2.76	< 0.001
	Model 3	0.78	2.18	1.70–2.80	< 0.001

Table 2. Logistic regression of MMS. MMS, medial meniscal slope; OR, odds ratio. Model 1: Unadjusted, Model 2: adjusted for BMI, injury side, time from injury, cause of injury and bone bruise, Model 3: adjusted for cause of injury and bone bruise.

if 10 hypotheses were tested, the original significance level of 0.05 was adjusted to 0.005 to maintain the overall error rate at the desired level.

Results

A total of 253 patients were included in the analysis, with 65 (25.69%) presenting with RL and 188 (74.31%) without RL. The convenience sample was comprised of 183 males and 70 females, with a mean age of 31.40 ± 7.06 years. Among these, 65 patients (25.7%) had ACL injuries accompanied by RL, while 188 patients had isolated ACL injuries. No significant differences in sex, age, BMI, or injury side were found between the groups. The RL group had higher contact injuries rate (36.9% vs. 19.2%, $P = 0.021$), MTS (7.41° vs. 6.15°, $P < 0.001$), steeper MMS (5.16° vs. 3.60°, $P < 0.001$), and higher bone bruises rate (20.0% vs. 8.5%, $P = 0.012$) (Table 1).

Predictive factors of RL

Logistic regression analyses were performed to evaluate the association between MTS, MMS, and the presence of RL across five models (Table 2 **and** Table 3). In the unadjusted model and adjusted models, showed significant ($P < 0.05$) associations for MTS (OR range = 1.73 to 1.75, $P < 0.001$) and MMS (OR range = 2.14 to 2.24, $P < 0.001$).

ROC result

The ROC analysis showed MTS had an AUC of 0.72 (95% CI 0.65–0.79, $P < 0.001$) with a cut-off value of 6.73°, resulting in a sensitivity of 71% and specificity of 67% (Youden index = 0.37). MMS had an AUC of 0.80 (95% CI 0.74–0.86, $P < 0.001$) with a cut-off value of 4.03°, yielding a sensitivity of 82% and specificity of 69% (Youden index = 0.51). (Table 4; Fig. 5).

Variable	Model	β	OR	95% CI	*P*
MTS	Model 1	0.56	1.75	1.42–2.17	< 0.001
	Model 2	0.55	1.73	1.39–2.15	< 0.001
	Model 3	0.55	1.73	1.40–2.14	< 0.001

Table 3. Logistic regression of MTS. MTS, medial tibial slope; OR, odds ratio. Model 1: Unadjusted, Model 2: adjusted for BMI, injury side, time from injury, cause of injury and bone bruise, Model 3: adjusted for cause of injury and bone bruise.

	Sensitivity	Specificity	Youden	Cut-off	AUC	95%CI	*P*
MMS	0.82	0.69	0.51	4.03	0.80	0.74–0.86	< 0.001
MTS	0.71	0.67	0.37	6.73	0.72	0.65–0.79	< 0.001

Table 4. ROC result. MMS, medial meniscal slope; MTS, medial tibial slope; AUC; area under curve; ROC: receiver operating characteristic.

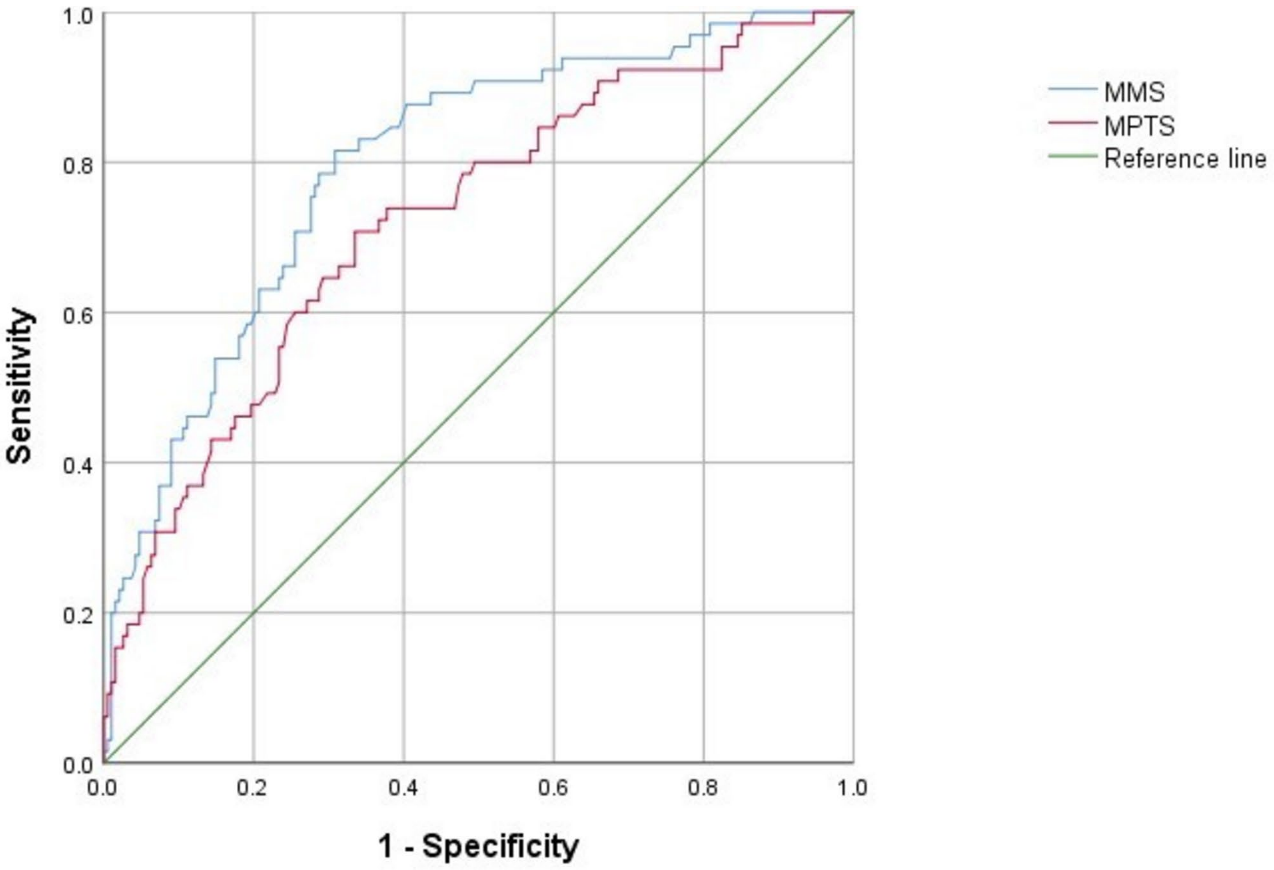

Fig. 5. The ROC curves for medial meniscal slope (MMS) and medial tibial slope (MTS) are depicted with respective colours. The AUC values are annotated on the graph.

Discussion

This study identified steeper MTS and MMS as significant predictive factors for the RL in patients with ACL injuries. Specifically, each one-degree increase in MTS and MMS was associated with a 2.18-fold and 1.73-fold increase in the odds of RL, after adjusting for confounding variables.

Our findings corroborate the results of previous studies[10,17], which also identified MTS and MMS as significant predictive factors for RL. However, discrepancies exist in the literature, with some studies reporting no association or only one of these parameters as a risk factor[9,13]. These inconsistencies may stem from differences in study design, sample sizes, measurement techniques, and the variables adjusted for in multivariable analyses.

By employing comprehensive multivariable models, our study mitigates the risk of confounders and provides more robust evidence supporting the role of MTS and MMS in RL development.

Ramp injuries are present in over 20% of ACL injuries. However, predictive factors for RL injuries are less studied. Previous research has identified sex[6–8,17–20], age[6–8,18,20], chronic injuries[6,7,18–20], contact injuries[8,17,20], and ACLR revision[7] as predictive factors for ACL injuries with concurrent RL. The findings between different studies are inconsistent, due to sample bias or the statistical methods used. Here, we showed MTS and MMS as predictive factors for RL using a multi-model strategy, including different variables sequentially, and confirmed these findings in traditional models, which included only parameters with significant differences in the initial variance analysis. Traditional models used in previous studies may overlook factors that, despite not showing significant differences, could still influence the regression results. Our multi-model strategy enhanced the robustness of the study by considering a broader range of variables, ensuring a more comprehensive analysis.

The biomechanical mechanisms underlying the association between steeper MTS and MMS and the development of RL are multifaceted. Following ACL injury, the anterior displacement of the tibia relative to the femur and femoral external rotation can cause impingement injuries and potentially lead to compressive damage at the posterior meniscotibial junction[21]. Posterior subluxation of the medial femoral condyle relative to the tibial plateau may also cause damage to the posterior meniscotibial junction. These mechanisms collectively increase the force applied to the posterior corner 73.9 N to 172.4 N[22], which may explain the high incidence of posterior horn injury in the medial meniscus following ACL injury. In ACL-deficient knees, the continued anterior displacement of the tibia leads to wedging of the posterior corner between the femur and tibia while being pulled by the semimembranosus attachment, ultimately resulting in RL[23]. Additionally, a steeper MMS can exacerbate the load on the posterior horn of the medial meniscus, increasing the likelihood of longitudinal tears characteristic of RL[11]. Biomechanical models suggest that a steeper MMS partially reverses the effects of a steeper TS, potentially limiting excessive anterior tibial translation and reducing tension on the ACL[24]. However, the increased force on the posterior corner of the meniscus due to steeper MMS may paradoxically worsen meniscal damage, leading to RL.

Our study identified a 25.69% incidence of RL in ACL injuries, which is lower than the 34.5% reported by Kim et al.[8]. yet similar to the 23.9% observed by Sonnery-Cottet et al.[7]. Given the substantial prevalence of RL, arthroscopic examination is warranted. Although arthroscopic confirmation is recognized as the diagnostic gold standard, reliance on conventional anterolateral viewing portal may result in diminishing sensitivity[25–27]. Consequently, the incorporation of alternative portals, the Gillquist view and the posteromedial portal, is recommended to optimize RLs detection rates in ACL injured patients[28,29].

The MMS showed a higher likelihood of RL compared to MTS. The cut-off value for sustaining a RL for MTS and MMS were 6.73° and 4.03°. The TS can be measured using various methods, including X-ray, computed tomography, and MRI. The disadvantage of using X-ray measurements is the difficulty in distinguishing between the medial and lateral tibial plateaus, due to the superimposition in lateral views[24]. In a comparative analysis, Naendrup et al.[30] reported that TS measurement discrepancies among CT, X-ray, and MRI can exceed 5°, with CT and MRI demonstrating higher consistency.

The ROC analysis revealed MMS achieved a higher area under the curve (AUC = 0.80) than the MTS (AUC = 0.72), indicating superior performance in predicting RL. MMS also demonstrated greater sensitivity (82%) and specificity (69%) relative to MTS, which yielded a sensitivity of 71% and specificity of 67%. Although MTS and MMS showed fair diagnostic ability (AUC > 0.7), the higher sensitivity of MMS suggests greater effectiveness in correctly identifying patients with RL, a critical factor for early diagnosis and intervention. The moderate specificity values indicate a reasonable capacity to exclude RL when measurements fall below established the established cut-off values. Consequently, MMS may serve as a more reliable parameter for preoperative assessments, aiding in patient stratification based on RL risk and guiding targeted intraoperative evaluations.

Both TS and MS represent predictive factors for RLs, with TS often receiving greater emphasis due to its characterization of proximal tibial morphology. However, knee biomechanics and the meniscus's role in limiting tibial anterior displacement[31] suggest MS may exert different effects compared to TS. Hohmann et al.[32] demonstrated that an increased MS can partially counterbalance TS and the wedging between the tibial plateau and femoral condyle, thereby limiting excessive anterior translation of the tibia, reducing ACL tension, and potentially mitigating ACL damage. The medial meniscus, characterized by a thin anterior and thick posterior region, more effectively moderates the influence of TS on knee mechanics, an effect that becomes increasingly greater with higher medial tibial plateau TS[24]. Biomechanical models further suggest a decrease in medial meniscus thickness, coupled with an increase in MMS, may elevate the load on the posterior horn of medial meniscus, contributing to the development of RL[11]. Thus, despite MS exhibiting a lower gradient relative to TS and potentially providing protection to the ACL, it may simultaneously increase the force on the posterior meniscal corner, thereby exacerbating meniscal damage such as RL.

This is study is not without limitations. First, its retrospective design may introduce selection bias and limit the ability to establish causality, despite the use of multivariable logistic regression to control for confounders. Second, many of the hypotheses proposed in our study have not been validated through biomechanical research; future studies should aim to provide a greater mechanistic understanding of these findings. Third, the measurement of TS and MS relied on the Hudek method applied to MRI data. The use of a 4 mm slice thickness may have reduced measurement accuracy. Thus, future studies might benefit from employing thinner MRI slices or 3D reconstructions to improve precision.

Conclusion

This study identifies increased MTS and MMS as significant predictive factors for RL in patients with ACL injuries, with MMS exhibiting a particularly strong association. The established cut-off values of 6.73° for MTS and 4.03° for MMS and demonstrate notable value in predicting RL. Clinicians should consider these anatomical parameters when assessing ACL-injured patients to enhance the detection and management of RL, ultimately improving knee stability and patient outcomes.

Data availability

Deidentified data for outcomes reported in this manuscript are available on request from the corresponding author for research purposes.

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References

1. Noyes, F. R. The function of the human anterior cruciate ligament and analysis of single- and double-bundle graft reconstructions. *Sports Health Jan.* **1**(1), 66–75. https://doi.org/10.1177/1941738108326980 (2009).
2. Diermeier, T. et al. Jun. Treatment after anterior cruciate ligament injury: Panther symposium ACL treatment consensus group. *Orthop J Sports Med.* **8**(6), 2325967120931097. (2020). https://doi.org/10.1177/2325967120931097
3. Boden, B. P., Sheehan, F. T., Torg, J. S. & Hewett, T. E. Noncontact anterior cruciate ligament injuries: Mechanisms and risk factors. *J. Am. Acad. Orthop. Surg. Sep.* **18**(9), 520–527. https://doi.org/10.5435/00124635-201009000-00003 (2010).
4. Simon, D., Mascarenhas, R., Saltzman, B. M., Rollins, M. & Bach, B. R. Jr., MacDonald P. The relationship between anterior cruciate ligament injury and osteoarthritis of the knee. *Adv. Orthop.* **2015**, 928301. https://doi.org/10.1155/2015/928301 (2015).
5. Thaunat, M. et al. Ramp lesion subtypes: prevalence, imaging, and arthroscopic findings in 2156 anterior cruciate ligament reconstructions. *Am. J. Sports Med.* **49**(7), 1813–1821. https://doi.org/10.1177/03635465211006103 (Jun 2021).
6. Liu, X. et al. Arthroscopic prevalence of ramp lesion in 868 patients with anterior cruciate ligament injury. *Am. J. Sports Med.* **39**(4), 832–837. https://doi.org/10.1177/0363546510388933 (Apr 2011).
7. Sonnery-Cottet, B. et al. Epidemiological evaluation of meniscal ramp lesions in 3214 anterior cruciate Ligament-Injured knees from the SANTI study group database: A risk factor analysis and study of secondary meniscectomy rates following 769 ramp repairs. *Am. J. Sports Med.* **46**(13), 3189–3197. https://doi.org/10.1177/0363546518800717 (Nov 2018).
8. Kim, S. H., Seo, H. J., Seo, D. W., Kim, K. I. & Lee, S. H. Analysis of risk factors for ramp lesions associated with anterior cruciate ligament injury. *Am. J. Sports Med.* **48**(7), 1673–1681. https://doi.org/10.1177/0363546520918207 (Jun 2020).
9. Willinger, L. et al. Medial meniscal ramp lesions in ACL-injured elite athletes are strongly associated with medial collateral ligament injuries and medial tibial bone bruising on MRI. *Knee Surg. Sports Traumatol. Arthrosc.* **30**(5), 1502–1510. https://doi.org/10.1007/s00167-021-06671-z (May 2022).
10. Park, Y. B. et al. The clinical application of machine learning models for risk analysis of ramp lesions in anterior cruciate ligament injuries. *Am. J. Sports Med.* **51**(1), 107–118. https://doi.org/10.1177/03635465221137875 (Jan 2023).
11. Song, G. Y. et al. Increased medial meniscal slope is associated with greater risk of ramp lesion in noncontact anterior cruciate ligament injury. *Am. J. Sports Med.* **44**(8), 2039–2046. https://doi.org/10.1177/0363546516640516 (2016).
12. Kim, S. H., Park, Y. B. & Won, Y. S. An increased lateral femoral condyle ratio is an important risk factor for a medial Meniscus ramp lesion including Red-Red zone tear. *Arthrosc.* **37**(10), 3159–3165. https://doi.org/10.1016/j.arthro.2021.03.078 (2021).
13. Tang, Z. et al. Investigation of the anatomic risk factors in acute anterior cruciate ligament ruptures to develop ramp lesions of the medial meniscus by quantitative MRI. *Insights Imaging* **3**(1), 133. https://doi.org/10.1186/s13244-024-01685-w (2024).
14. Vandenbroucke, J. P. et al. Strengthening the reporting of observational studies in epidemiology (STROBE): Explanation and elaboration. *PLoS Med.* **16**(10), e297. https://doi.org/10.1371/journal.pmed.0040297 (2007).
15. Hudek, R., Schmutz, S., Regenfelder, F., Fuchs, B. & Koch, P. P. Novel measurement technique of the tibial slope on conventional MRI. *Clin. Orthop. Relat. Res.* **467**(8), 2066–2072. https://doi.org/10.1007/s11999-009-0711-3 (2009).
16. Wang, X. et al. Effects of medial meniscal slope and medial posterior tibial slope on the locations of meniscal tears: A retrospective observational study. *Med. (Baltimore)* **20**(47), e23351. https://doi.org/10.1097/md.0000000000023351 (2020).
17. Balazs, G. C. et al. Ramp lesions of the medial Meniscus in patients undergoing primary and revision ACL reconstruction: Prevalence and risk factors. *Orthop. J. Sports Med.* **7**(5), 2325967119843509. https://doi.org/10.1177/2325967119843509 (May 2019).
18. DePhillipo, N. N. et al. Incidence and detection of meniscal ramp lesions on magnetic resonance imaging in patients with anterior cruciate ligament reconstruction. *Am. J. Sports Med.* **45**(10), 2233–2237. https://doi.org/10.1177/0363546517704426 (Aug 2017).
19. Di Vico, G. et al. Correlation between time from injury to surgery and the prevalence of ramp and hidden lesions during anterior cruciate ligament reconstruction. A new diagnostic algorithm. *Muscles Ligaments Tendons J. Jul-Sep.* **7**(3), 491–497. https://doi.org/10.11138/mltj/2017.7.3.491 (2017).
20. DePhillipo, N. N. et al. Clinical characteristics and outcomes after primary ACL reconstruction and Meniscus ramp repair. *Orthop. J. Sports Med.* **8**(4), 2325967120912427. https://doi.org/10.1177/2325967120912427 (Apr 2020).
21. Guy, S. et al. Isolated meniscotibial ligament rupture: The medial Meniscus belt lesion. *Arthrosc. Tech.* **11**(2), e133–e138. https://doi.org/10.1016/j.eats.2021.09.013 (2022).
22. Shu, L., Abe, N., Li, S. & Sugita, N. Importance of posterior tibial slope in joint kinematics with an anterior cruciate ligament-deficient knee. *Bone Joint Res.* **11**(10), 739–750. https://doi.org/10.1302/2046-3758.1110.Bjr-2022-0039.R1 (2022).
23. LI, S. et al. Biomechanical comparison of anterior cruciate ligament tear accompanied with ramp injury and their repairs in cadaver knees. *Orthop. J. China* **30**(16), 1492–1496 (2022).
24. Hohmann, E., Tetsworth, K., Glatt, V., Ngcelwane, M. & Keough, N. Medial and lateral posterior tibial slope are independent risk factors for noncontact ACL injury in both men and women. *Orthop. J. Sports Med.* **9**(8), 23259671211015940. https://doi.org/10.1177/23259671211015940 (Aug 2021).
25. Keyhani, S. et al. Is posterior knee arthroscopy using posterior portals necessary for orthopedic surgeons? The latest evidence on applications and techniques. *EFORT Open. Rev.* **25**(4), 189–198. https://doi.org/10.1530/eor-22-0133 (2023).
26. Kim, S. H., Lee, S. H., Kim, K. I. & Yang, J. W. Diagnostic accuracy of sequential arthroscopic approach for ramp lesions of the posterior Horn of the medial Meniscus in anterior cruciate Ligament-Deficient knee. *Arthrosc.* **34**(5), 1582–1589. https://doi.org/10.1016/j.arthro.2017.12.008 (2018).
27. Malatray, M. et al. Ramp lesions in ACL deficient knees in children and adolescent population: A high prevalence confirmed in intercondylar and posteromedial exploration. *Knee Surg. Sports Traumatol. Arthrosc. Apr.* **26**(4), 1074–1079. https://doi.org/10.1007/s00167-017-4471-4 (2018).
28. Bumberger, A. et al. Ramp lesions are frequently missed in ACL-deficient knees and should be repaired in case of instability. *Knee Surg. Sports Traumatol. Arthrosc. Mar.* **28**(3), 840–854. https://doi.org/10.1007/s00167-019-05521-3 (2020).
29. Ahn, J. H., Bae, T. S., Kang, K. S., Kang, S. Y. & Lee, S. H. Longitudinal tear of the medial meniscus posterior Horn in the anterior cruciate ligament-deficient knee significantly influences anterior stability. *Am. J. Sports Med.* **39**(10), 2187–2193. https://doi.org/10.1177/0363546511416597 (Oct 2011).

30. Naendrup, J. H. et al. High variability of tibial slope measurement methods in daily clinical practice: Comparisons between measurements on lateral radiograph, magnetic resonance imaging, and computed tomography. *Knee Jun* **27**(3), 923–929. https://doi.org/10.1016/j.knee.2020.01.013 (2020).
31. Grassi, A. et al. Medial and lateral meniscus have a different role in kinematics of the ACL-deficient knee: A systematic review. *J. ISAKOS* **4**(5), 233–241. https://doi.org/10.1136/jisakos-2019-000293 (2019). 2019/09/01.
32. Hohmann, E., Tetsworth, K., Glatt, V., Ngcelwane, M. & Keough, N. Increased posterior slope of the medial and lateral Meniscus posterior Horn is associated with anterior cruciate ligament injuries. *Arthrosc.* **38**(1), 109–118. https://doi.org/10.1016/j.arthro.2021.04.066 (2022).

Author contributions

X. W. was responsible for the conception and design of the study and data collection; K. L. and L. J. were involved in the processing and statistical analysis of data; X. W. and L. Y. were involved in the drafting of the manuscript. S. D. and J. Y. revised the manuscript. All the authors finally approved the manuscript. J. L. takes responsibility for the integrity of the work as a whole. All authors have read and agreed to the published version of the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval

This study adheres to the Declaration of Helsinki and has been approved by the Medical Ethics Committee of Affiliated Hospital of Shandong University of Traditional Chinese Medicine, ethical approval number: (2023) Lunshen No. (136) - KY.

Additional information

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