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The Depth of the Lateral Femoral Notch Sign: Its Significance in Acute Anterior Cruciate Ligament Tears with Concomitant Posterior Root Tears of the Lateral Meniscus

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Abstract: *Background:* Anterior cruciate ligament (ACL) tears are frequently accompanied by lateral meniscus posterior root tears (LMPRT), which worsen prognosis. The lateral femoral notch sign (LFNS), a radiographic depression on the lateral femoral condyle, has been linked to ACL injury, yet its association with LMPRT and post-operative function remains unclear. This study examined whether LFNS depth predicts LMPRT and influences short-term functional outcomes after ACL reconstruction. *Purpose:* To investigate the relationship between the LFNS and functional outcomes in patients with acute ACL tears undergoing surgery and to explore the potential of LFNS as a predictive sign for ACL injuries combined with LMPRT. *Methods:* A total of 89 patients with ACL tears were enrolled in this retrospective pilot study between December 2020 and December 2023. All enrolled patients were divided into two groups based on LMPRT: the ACL group (ACL tear alone) and the LMPRT group (ACL tear combined with concomitant LMPRT). In addition to demographic data, the following parameters were compared: the incidence and depth of LFNS, functional results (Lysholm score) at 6 and 12 months, VAS score, and ROM before and after surgery. A logistic regression model was used to identify potential risk factors for ACL injury with concurrent LMPRT. *Results:* Among the 89 enrolled patients, 64 patients (71.9%) were in the ACL group, whereas 25 patients (28.1%) were in the LMPRT group. LMPRT was found to be correlated with the depth of LFNS ($P < 0.001$), and logistic regression analysis demonstrated that age, depth of LFNS, and LMPRT were correlated with the 12-month functional results ($P = 0.001$, $P = 0.035$, $P = 0.010$). The 12-month functional results were better in the LMPRT group ($P < 0.001$); however, no significant difference was found in the 6-month functional results between the ACL group and the LMPRT group ($P = 0.272$). The ROM in the ACL group was 118.44 ± 10.35 at 12 months post-operatively ($P = 0.031$), which was significantly greater than that in the LMPRT group (113.20 ± 9.45). However, no significant differences were observed at any other time points. *Conclusion:* LFNS may be a potential indicator of the LMPRT in patients with ACL tears. LFNS had an impact on the 12-month functional results in the LMPRT group but not on the 6-month functional results. Age, depth of LFNS, and LMPRT are risk factors for 12-month functional results.

Keywords: Lateral femoral notch sign; Anterior cruciate ligament tear; Posterior root tears of the lateral meniscus; Risk factors; Functional outcomes

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1. Introduction

As the most common type of sports injury, anterior cruciate ligament (ACL) tears usually occur during sporting activities or traffic accidents. There are approximately 200,000 ACL injuries in the United States each year, and in Japan, there are approximately 3,000 ACL injuries in middle and high school athletes each year, with an injury rate of 0.80/1000 [1]. The ACL is a major stabilizing ligament of the knee, and rupture often increases the risk of articular cartilage damage, meniscal degeneration, and functional instability. Lateral meniscus posterior root tear (LMPRT) is not uncommon in these patients. The incidence of LMPRT is 7–12% in ACL-injured patients, which may cause persistent knee instability and knee joint arthritis even after ACL reconstruction [2,3]. However, there is currently no consensus about the early diagnosis of LMPRT.

The lateral femoral notch sign (LFNS) is defined as an indentation found in the lateral femoral condyle, which results from the impaction of a pivot shift injury (**Figure 1**). Berthold *et al.* reported that LFNS occurred in 40% of patients with combined ACL and lateral meniscal tears [4], whereas Herbst *et al.* reported that every 1 mm increase in notch depth doubled the odds of lateral meniscal lesions [5]. However, it remains unclear whether LFNS can specifically predict LMPRT or whether the depth of LFNS influences postoperative function.

Figure 1. A deep lateral femoral notch sign on sagittal T2-weighted magnetic resonance imaging in a patient with ACL tear and concomitant with PLRT surgical techniques and rehabilitation

On the basis of these findings, we hypothesized that LFNS might be a potential predictor associated with ACL injuries combined with LMPRT. The present study aimed to detect the significance of LFNS in patients with ACL rupture with concomitant LMPRT. Furthermore, the potential risk factors associated with functional prognosis were also evaluated.

2. Materials and methods

2.1. Study design and participants

This protocol was approved by the Ethics Review Committee of Changzhou Hospital Affiliated to Nanjing University of Chinese Medicine. Informed consent was obtained from all participants.

From December 2020 to December 2023, a total of 89 patients who underwent surgical treatment for ACL tear, 37 females and 52 males, aged 37.8 ± 13.9 (range, 13–69) years, were retrospectively analyzed. A total of 101 people were initially included in the study, and 12 patients were excluded because of the absence of an MRI or a history of previous knee surgeries. The mechanisms of injury were investigated and categorized into sports-related, traffic accidents, sprains, falls, or other types of injuries. The study compared age, sex, BMI, injury cause, time from injury to MRI, preoperative VAS score, and ROM between the two groups. The baselines are delineated in **Table 1**.

Table 1. Characteristics of patients

	ACL group (64)	LMPRT group (25)	*P* value
Age (year)	38.08 ± 14.16	37.32 ± 13.98	0.957
Gender (male/female)	38/26	14/11	0.814
BMI (kg m^{-2})	25.33 ± 3.32	23.92 ± 2.79	0.243
Depth of LFNS (mm)	1.61 ± 0.47	2.15 ± 0.50	0.000
Causes of injury (sports/ traffic/sprain/Fall/ others)	13/13/15/18/5	10/6/3/2/4	0.078
ASA (I/II)	63/1	24/1	0.485
Complications (yes/no)	2/62	0/25	0.922
Time from injury to MRI (days)	24.53 ± 25.50	15.68 ± 23.40	0.177

Continuous variables are presented as mean ± standard deviation (range); categorical variables as number (percentage).

BMI, body-mass index; LFNS, lateral femoral notch sign; ASA, American Society of Anesthesiologists physical-status classification; Time from injury to MRI denotes the interval between the day of initial trauma and the day of the first MRI examination.

Participants were eligible if they were first-time ACL ruptures and had no prior knee injuries or operations on either limb. Patients were excluded if they had incomplete clinical data; if they had ACL avulsion fractures; if they had combined intra-articular and periarticular fractures of the knee; if they had neurovascular injury; if they had contralateral ACL injury; or if they had concomitant posterior cruciate ligament injury and severe medial collateral ligament or posterolateral complex injury requiring operative treatment. The patient selection process is shown in **Figure 2**.

We assessed the presence of lateral meniscus injury during ACL reconstruction. LMPRT was defined as a radial tear occurring within a 10-mm distance from the insertion of the lateral meniscus posterior root [6]. If intraoperative arthroscopy reveals an LMPRT, the peripheral margin of the lateral meniscus will be trimmed. The ruptured portion was subjected to all-inside repair via a suture device (Ethicon FastFix System, Johnson &

Johnson, USA). Meniscal tension was assessed by probing after repair to ensure physiological stability. In cases where no tear is detected in the lateral meniscus during exploration, meniscal tension is assessed and confirmed to be appropriate. All enrolled patients were divided into two groups according to their LMPRT status: the ACL group (ACL tear alone) and the LMPRT group (ACL tear combined with concomitant LMPRT).

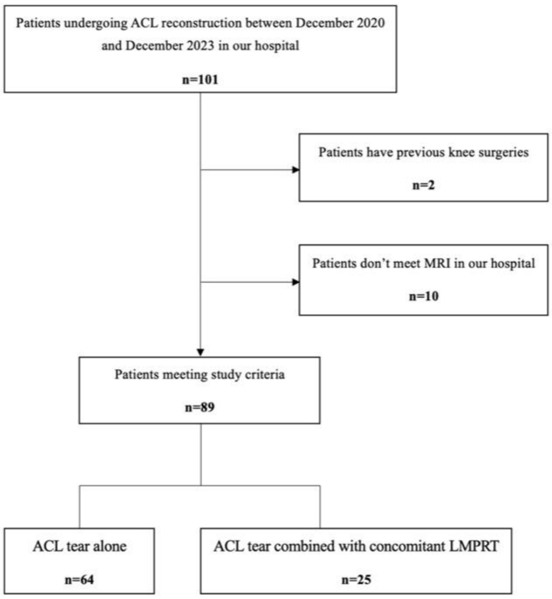

Figure 2. Flowchart displaying patients included for study analysis

2.2. Radiographic evaluation

The depth of LFNS was independently assessed, and the data were extracted by reviewing records of surgery and preoperative MR images obtained by two different researchers via the PACS system. The depth of the LFNS was measured on the sagittal MR slice that displayed the deepest point of the sulcus. Using the tangent method, a straight line was drawn between the most anterior and most posterior prominences of the lateral femoral condylar notch; the perpendicular distance from this tangent line to the deepest point of the recess was recorded in millimeters (**Figure 3**) [7].

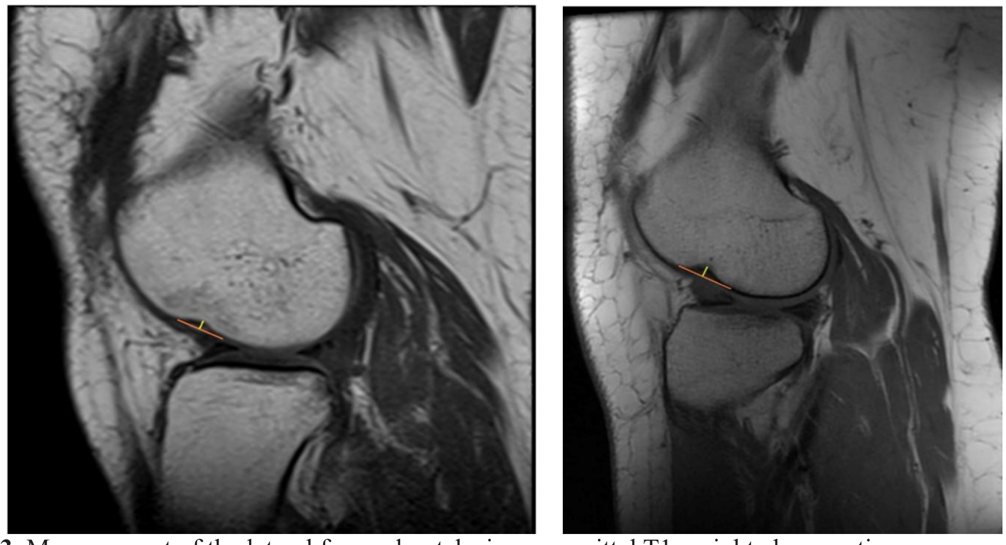

Figure 3. Measurement of the lateral femoral notch sign on sagittal T1-weighted magnetic resonance imaging

2.3. Surgical techniques and rehabilitation

All surgeries were performed by the same surgeon majoring in sports medicine under general anesthesia or epidural anesthesia. These patients underwent anatomical single-bundle ACL reconstruction via the autologous peroneal long tendon. Following the postoperative rehabilitation protocol at our institution, isometric knee tendon exercises were started immediately after surgery. This protocol involves a restricted range of motion from 0° to 90° and partial weight-bearing as tolerated during the first two weeks post-operatively. Subsequently, full weight-bearing and an unrestricted range of motion followed. The joint movement of the knee fully recovered approximately three months post-operatively.

2.4. Functional evaluation

All patients were followed up at 1, 3, 6, and 12 months post-surgery. The following parameters were used:

The visual analog scale (VAS): The VAS, a widely recognized tool for quantifying subjective pain intensity from 0 to 10, was utilized by two physicians to evaluate functional outcomes both before and after surgery.

Range of motion (ROM): The ROM of the knee, including flexion and extension, was measured with a goniometer by one orthopedic physician blinded to both groups.

Lysholm score: This score consists of 8 items scored on a 0–100 scale, assessing pain, limp, locking, instability, swelling, stair climbing, squatting, and the need for support (e.g., crutches). Higher scores indicate better knee function. Two physicians evaluated the functional results at 6 or 12 months post-operatively to ensure the reliability of the results.

2.5. Statistical analysis

Statistical analysis was performed with SPSS 24.0 (SPSS Inc., Chicago, IL, USA). The normality of continuous variables was first assessed via the Kolmogorov–Smirnov test; thereafter, parametric or nonparametric tests were selected accordingly. Continuous variables passing normality are presented as the mean ± standard deviation (SD), whereas those failing the test are expressed as medians (interquartile ranges, 25th–75th percentiles). The differences or associations between groups were examined by independent-samples *t*-tests for continuous variables and χ^2 tests for categorical variables. Multivariate analysis was then applied to identify independent predictors of 12-month functional outcome. Lysholm scores were compared at each follow-up time point. A two-tailed *P* value < 0.05 was considered statistically significant.

3. Results

3.1. Patient characteristics and baseline data

The final study cohort comprised 89 patients (58.4% male). Of the total patients, 64 (71.9%) had an isolated ACL tear, while 25 patients (28.1%) presented with a concomitant LMPRT. And 11 (17.19%) patients had LFNS, while 17 (68.0%) presented with LFNS. LFNS was observed in 11 (17.19%) patients of the ACL group, whereas LFNS was noted in 17 (68.0%) cases of the PLRT group. All 89 operative wounds united uneventfully with no superficial or deep infection. Additionally, 97.7% of patients resumed their activities of daily living, had regained normal gait, and resumed their previous work. All patients resumed their activities of daily living, had regained normal gait, and resumed their previous work. Only two complications (1 knee joint effusion and 1 postoperative pain) occurred postoperatively.

3.2. VAS score and ROM

The VAS score and ROM improved in both groups ($P < 0.001$) at the latest follow-up. There was no difference in the VAS score between the two groups before or after surgery. However, in terms of joint ROM, there was a difference between the two groups at 12 months post-operatively ($P = 0.031$, **Table 2**), but no difference was found at any other time point.

Table 2. The VAS score and ROM of patients

Variables	ACL group (64)	LMPRT group (25)	*P* value
VAS score			
Pre-operation	3.04 ± 0.94	3.556 ± 0.71	0.462
1m postoperatively	2.39 ± 0.79	2.28 ± 0.74	0.547
3m postoperatively	1.45 ± 0.96	1.40 ± 0.87	0.810
6m postoperatively	0.20 ± 0.57	0.44 ± 0.77	0.114
ROM			
Pre-operation	49.77 ± 8.52	49.60 ± 7.49	0.932
1m postoperatively	97.66 ± 6.17	97.60 ± 6.31	0.969
3m postoperatively	104.30 ± 6.66	105.60 ± 5.65	0.390
6m postoperatively	110.70 ± 9.46	112.80 ± 9.47	0.350
12m postoperatively	118.44 ± 10.35	113.20 ± 9.45	0.031

Visual-analogue scale (VAS) pain scores and active range of motion (ROM) before surgery and at 1, 3, 6, and 12 months post-operatively.

Values are mean ± standard deviation. VAS is recorded on a 0–10 point scale; ROM is reported in degrees (°).

3.3. Prognostic factors for 12-month functional results postoperatively

Logistic regression analysis confirmed that age, depth of LFNS, and LMPRT were correlated with the 12-month functional results ($P < 0.05$, **Table 3**).

Table 3. Logistic regression analysis of risk factors in 12-month functional results

	B	S.E.	Wald	*P* value	EXP (β)	EXP (β) with 95 % confidence intervals	
						Lower	Upper
Age (≥37.8/<37.8)	-0.121	0.036	11.338	0.001	8.463	2.162	33.122
Gender (male/female)	0.356	0.952	0.140	0.708			
BMI (≥24.0/<24.0)	0.520	0.928	0.314	0.575	0.595	0.195	1.814
Causes of injury (sports/ traffic/sprain/fall/ others)	0.421	0.268	2.471	0.116	0.361	0.044	2.953
ASA (I/II)	-18.443	27327.501	0.000	0.999	10.659	1.65	234.543
Complications (yes/no)	0.599	2.562	0.055	0.815	2.160	0.042	111.390
Time from injury to MRI (4 weeks or not)	0.004	0.012	0.089	0.765	1.082	0.323	3.623
Depth of LFNS (1.7 mm≥24.0/<1.7 mm)	-1.441	0.682	4.469	0.035	1.368	0.393	4.762
LMPRT	-1.957	0.764	6.566	0.010	7.443	1.603	34.567

CI, confidence interval. LFNS depth is expressed in millimeters

3.4. The functional results at 6 and 12 months between the ACL group and the LMPRT group

The 6-month functional results did not differ significantly between the ACL group and the LMPRT group (P = 0.272, **Table 4**). However, the 12-month functional results were better in the LMPRT group ($P < 0.001$, **Table 4**).

Table 4. Functional results

	ACL group (64)	LMPRT group (25)	*P* value
6 month	77.31 ± 5.19	75.96 ± 5.19	0.272
12 month	85.81 ± 3.59	82.08 ± 4.03	0.000
P	0.000	0.000	

Values are mean ± SD (range). Lysholm score ranges from 0 to 100 points; higher scores indicate better function.

3.5. Complications

No serious complications were reported in either group. Only two complications (1 case of knee joint effusion and 1 case of postoperative pain) occurred postoperatively. No other complications (such as secondary injury, incision, or intra-articular infection) were reported.

4. Discussion

The findings of this study indicated that the LMPRT was associated with the depth of LFNS, and logistic regression analysis demonstrated that age, depth of LFNS, and LMPRT were correlated with the 12-month functional results. The 12-month functional results were better in the LMPRT group; however, no significant difference was found in the 6-month functional results between the ACL group and the LMPRT group. The ROM in the ACL group was 118.44 ± 10.35 at 12 months post-operatively (P = 0.031), which was significantly greater than that in the LMPRT group (113.20 ± 9.45). However, no significant differences were observed at any other time points.

LMPRT in patients who have ACL injuries affects the rotational stability of the knee joint [8]. Currently, MRI is regarded as an important and noninvasive tool for the detection of LMPRT [9]. However, according to a recent study by Krych *et al.*, nearly 70% of LMPRT injuries were overlooked during preoperative MRI assessments [10]. This high rate of misdiagnosis significantly impacts clinical decision-making regarding surgical interventions, potentially resulting in a delay in the diagnosis and subsequent treatment of LMPRT and even an entirely missed diagnosis. LMPRT can significantly reduce hoop strain tension and increase articular cartilage contact pressure. Over time, this may trigger early focal cartilage defects and eventual osteoarthritis [11]. Moreover, postoperative functional recovery of the knee joint is still a major challenge. Consequently, it is particularly critical to identify indirect indicators with better diagnostic value. Understanding the potential risk factors for LMPRT in a timely manner may help clinicians find injuries as quickly as possible, which will prevent subsequent damage and arthritic degeneration and reestablish knee performance.

LFNS is considered the most severe form of bone contusion and microfracture. However, there is still controversy about the formation mechanism of LFNS. Some researchers have hypothesized that LFNS may arise from bony microdamage precipitated by the valgus load that accompanies the original ACL tear. Prior studies have shown that LFNS is a reliable secondary indicator for ACL injury and should not be missed if it is deeper than 1.5 mm. Dimitriou *et al.* proposed that a deep LFNS is a clinically useful diagnostic marker for concurrent ACL/ALL rupture [12].

Therefore, LFNS should raise suspicion for associated injury in the knee joint to guide surgery and prevent misdiagnosis. Their study also suggested that deeper LFNS was found in patients with lateral meniscal plus ACL injuries than in those with isolated ACL injuries on preoperative MRI. We also reached a similar conclusion. In the present study, the LMPRT was also confirmed to be correlated with the depth of LFNS ($P < 0.001$).

Although LFNS is clinically significant, few treatments exist for its management. In most cases, LFNS has only radiographic relevance, with no need for surgical intervention. Several studies have reported that there is no evidence indicating that LFNS should be addressed surgically [5]. Others believe that a reduction in LFNS can postpone future osteoarthritis. However, further studies are necessary to validate this hypothesis. In our work, logistic regression analysis confirmed that the depth of LFNS was correlated with the 12-month functional results ($P < 0.05$). Additionally, many studies have used knee function scores to evaluate patient degeneration, revealing that individuals with LFNS exhibit a degree of knee joint degeneration. Further evaluation is necessary to determine the appropriate subsequent therapy. In addition, whether the depth of LFNS is positively correlated with the severity of the injury also needs further exploration. We should pay attention to potential medial collateral ligament and lateral meniscus injuries in patients with ACL tear concomitant with a positive femoral notch sign. These events are more likely to occur together.

The present study revealed that the presence of LMPRT was not significantly associated with the time interval from injury to MRI examination ($P = 0.177$). Specifically, the mean interval from injury to MRI was 24.53 ± 25.50 days in the ACL injury group and 15.68 ± 23.40 days in the LMPRT group. A previous study confirmed that the incidence of LMPRT is not influenced by the time interval between injury and MRI or surgical intervention [13]. However, some studies have reached opposite conclusions. A longer delay between injury and surgical treatment may be associated with an increased incidence of LMPRT [14]. Bone bruises following an ACL tear are most commonly observed in the lateral compartment of the knee, typically resulting from a pivot shift mechanism involving valgus stress and rotational forces. The characteristic distribution of bone bruises in the lateral compartment indicates that the lateral meniscus may become entrapped and compressed between the femoral condyle and tibial plateau during injury, potentially contributing to the occurrence of lateral meniscus injuries. Sohn et al. reported that ACL-injured patients with concomitant bone bruises presented a significantly greater incidence of lateral meniscus and tibiofemoral cartilage injuries than did those without bone bruises, suggesting a strong association between the presence of bone bruising and additional intra-articular injuries [15]. Mester et al. demonstrated that, regardless of the morphology of bone bruises, all patients experienced significant improvements in subjective functional outcomes, quality of life, and muscle strength over time [16].

In our work, to identify factors influencing the prognosis of functional outcomes at 12 months, logistic regression analysis confirmed that age, depth of LFNS, and LMPRT were significantly associated with 12-month functional outcomes. In addition, in terms of joint range of motion, there was a difference between the two groups at 12 months post-operatively ($P = 0.031$), but no difference was found at any other time point. In summary, the presence of LMPRT may compromise knee joint function following ACL reconstruction. Particularly in young individuals, who often have greater demands for physical activity and sports participation, early intervention for LMPRT becomes even more critical. Previous studies have shown that the lateral meniscal posterior root is crucial for controlling anterior tibial translation in the pivot shift test. Additionally, the lateral meniscus posterior root serves as a vital stabilizer against internal rotation, with contributions from the meniscofemoral ligaments enhancing this stability. Therefore, preserving root anatomy is vital for proper load transfer. Many researchers believe that radial displacement of the lateral meniscus may increase arthritis risk, highlighting the importance of

LMPRT repair. Thus, more clinical studies are needed to clarify its link with lateral compartment arthritis. Filardo *et al.*'s recent meta-analysis [17] revealed that subchondral fractures and bone bruising locations may adversely affect clinical outcomes and full recovery after ACL reconstruction. Therefore, early LMPRT repair may promote meniscal healing and thereby contribute to long-term knee preservation [18]. Jeon *et al.* reported that full repair could be achieved in approximately 80.3% of patients with posterior horn lateral meniscal oblique radial tears (LMORTs). Patient-reported outcome measures improved significantly [19].

5. Limitations

The present study has several limitations. First, this was a retrospective study with a small sample size, which limits scientific objectivity. Future studies with larger sample sizes are needed to confirm our findings. Second, this study lacked intraoperative or arthroscopic data. Future research incorporating these measurements could help establish correlations between preoperative MRI-detected LFNS depth and actual posterior root tear size observed during surgery, thereby enhancing clinical decision-making processes. Third, data from the contralateral uninjured knee were not collected to assess individual physiological variations in the LFNS. Fourth, this retrospective study was performed at our own hospital, and multicenter, larger-sample studies are needed.

6. Conclusion

The present study revealed that the presence of LFNS may be a potential indicator for LMPRT in patients with ACL tears. LFNS had an impact on the 12-month functional results in the LMPRT group but not on the 6-month functional results. Age, depth of LFNS, and LMPRT are risk factors for 12-month functional results. However, to make definitive treatment recommendations for LFNS, further prospective controlled trials are necessary.

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The authors declare no conflict of interest.

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