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Research Article

Keywords:

Posted Date: August 11th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10395468/v1>

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Additional Declarations: No competing interests reported.

EVALUATION OF THE LATERAL FEMORAL NOTCH SIGN AS A DIAGNOSTIC TEST FOR ANTERIOR CRUCIATE LIGAMENT RUPTURE

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ABSTRACT

Objectives : The primary objective of this study is to evaluate the diagnostic properties of measuring the lateral femoral notch on lateral knee radiographs in cases of acute trauma for the diagnosis of anterior cruciate ligament (ACL) tears.

Materials and Methods : This is a monocentric retrospective study assessing the diagnostic properties of a test based on data from patients who presented with knee trauma at the emergency trauma department from October 2020 to December 2022. Inclusion criteria included the performance of knee radiographs (anteroposterior and lateral views) in primary care and subsequent MRI. A group with confirmed ACL tear diagnosed via MRI was compared to a control group where MRI ruled out any central pivot lesions. Radiographic analysis evaluated the presence of a notch and, if present, its depth.

Results : A total of 412 patients were included in our study. Patients with ACL tears had a deeper lateral femoral notch (LFNS) on average (0.677 ± 0.613 mm) compared to injury-free patients (0.214 ± 0.206 mm). A notch depth threshold of 1 mm exhibited interesting and discriminative diagnostic characteristics, with a calculated specificity of 98.5% and a positive likelihood ratio of 21.3. This sign was present in 31.1% of patients with ACL tears. For a threshold set at ≥ 1 mm notch depth, we found no statistically associated peripheral ligament, meniscal, or chondral lesions linked to ACL tears. However, among patients with ACL tears and an LFNS ≥ 1 mm, contact pivot sports were significantly overrepresented. Finally, the evaluation of a composite criterion combining initial clinical suspicion and the presence of an LFNS ≥ 1 mm further enhanced the test's discriminatory capacity, yielding a specificity of 99.5%.

Conclusion : The measurement of LFNS ≥ 1 mm confirms with 99.5% specificity the diagnosis of anterior cruciate ligament (ACL) tear when clinical hemarthrosis is present in the context of acute knee trauma.

INTRODUCTION :

Acute knee injuries are among the leading causes for consultations in sports traumatology¹⁰. Ligamentous injuries of the knee constitute the most common traumatic manifestations encountered in various pivot-contact sports^{1,7,12}. In regions where winter sports dominate seasonal activities, skiing emerges as a major contributor to these types of injuries. An analysis of 250,000 patients with winter-related injuries reveals that the knee is the most frequently affected joint, accounting for over 30% of all injuries, with approximately 15% being anterior cruciate ligament (ACL) tears¹¹. These injuries predominantly impact a young and athletic population, for whom surgical reconstruction of the ACL and treatment of associated meniscal injuries are frequently indicated.

In emergency settings, confirming a diagnosis can be challenging due to the difficulty of conducting a reliable clinical examination and the limited availability of rapid access to MRI in certain regions. When diagnosis is not established during the initial emergency consultation, patients who do not receive appropriate management may develop chronic joint instability, potentially leading to meniscal and cartilage injuries⁹.

Accurate and reliable diagnosis of ACL rupture in primary care appears essential in order to refer the patient to the appropriate healthcare pathway. As the clinical examination and the X-ray are the two available data in primary care, diagnosis process should be optimized based on them.

The lateral femoral notch sign, visible on standard lateral X-Ray has been described as a sign of acute ACL rupture^{8,14,16,17}. It is secondary to the excessive anterior tibial translation leading to a significant impact between the posterior edge of the tibial plateau and the lateral femoral condyle. Bone bruise observed on Early post trauma MRI confirms this biomechanical pattern.

Without clear threshold for LFNS depth, the use of LFNS in daily practice remains unconsensual^{8,16}.

The recent study by Lodewijks et al. reports good intra- and inter-observer variability, along with high specificity, which is valuable for referring patients with a lateral femoral notch sign (LFNS) >1 mm to specialized care pathways. However, the study is limited by a relatively small patient cohort¹³.

To solve these current limitations, the aim of our study is to confirm the efficiency of the 1mm threshold for LFNS to diagnose ACL rupture in acute settings on a large cohort. Secondary objective was to evaluate a composite criterion including LFNS and clinical suspicion (hemarthrosis).

MATERIALS AND METHODS

Study Design and Population This was a single-center, retrospective case-control study evaluating the diagnostic performance of a test. The study was conducted between October 1, 2020, and December 31, 2022, in the trauma emergency department of Grenoble Alpes University Hospital (CHU Grenoble Alpes).

The study flowchart is presented in.

Patients aged 15 to 55 years were included if they presented with acute knee trauma (≤ 5 days) and had undergone standardized anteroposterior and lateral knee radiographs (with perfect superimposition of both femoral condyles) in the emergency department, subsequent knee MRI and follow-up consultation with an orthopedic surgeon at CHU Grenoble Alpes to determine whether the initial trauma caused a complete ACL rupture.

Patients were excluded if they did not meet the inclusion criteria, were lost to follow-up, had a history of anterior cruciate ligament (ACL) rupture in the injured knee, had a history of osteochondritis, arthritis, fracture, surgery on the injured knee or any condition that could have lead to any abnormal radiographs pattern of the femoral condyles

Patients were allocated to the case group if ACL rupture was confirmed by both MRI and orthopedic surgeon assessment. Patients with an intact ACL, as confirmed by MRI and clinical evaluation, were allocated to the control group.

Patients with indeterminate MRI findings regarding ACL status (e.g., "suspected ACL tear" or "partial ACL tear") were excluded from the study (n=9).

For all included patients, the following data were collected:

- Demographics: age, sex, height, weight, laterality of the injured knee, and medical history.
- Trauma circumstances: categorized according to Hefti et al. ⁵ as high-risk pivot sports, low-risk pivot sports, non-pivot sports, or other situations.
- Radiographic findings: presence of a lateral femoral notch sign (LFNS), depth of LFNS, Second fracture, and tibial spine avulsion.
- MRI findings: associated meniscal lesions and chondral impaction fractures.
- Clinical evaluation at the emergency department: Range of motion, pain (visual analogic scale) and the presence or absence of hemarthrosis of the injured knee

Radiological Measurement

The depth of the LFNS on lateral knee radiographs was measured using the technique described by Warren et al¹⁵. A tangential line was drawn along the articular surface of the lateral femoral condyle at the level of the notch, crossing the most anterior and posterior points of the femoral notch (thick arrow on the X-ray). The measurement was taken as the perpendicular distance from this tangent to the deepest point of the notch (double arrow on the zoomed X-ray) (Image 1).

The image viewing software (PACS) allowed the use of a magnifying function and a scale marked in 0.1 mm increments. Measurements were performed independently by two emergency physicians who were blinded to the MRI findings and the orthopedic surgeon's conclusion. For each patient, the mean of the two measurements was used to define the notch depth.

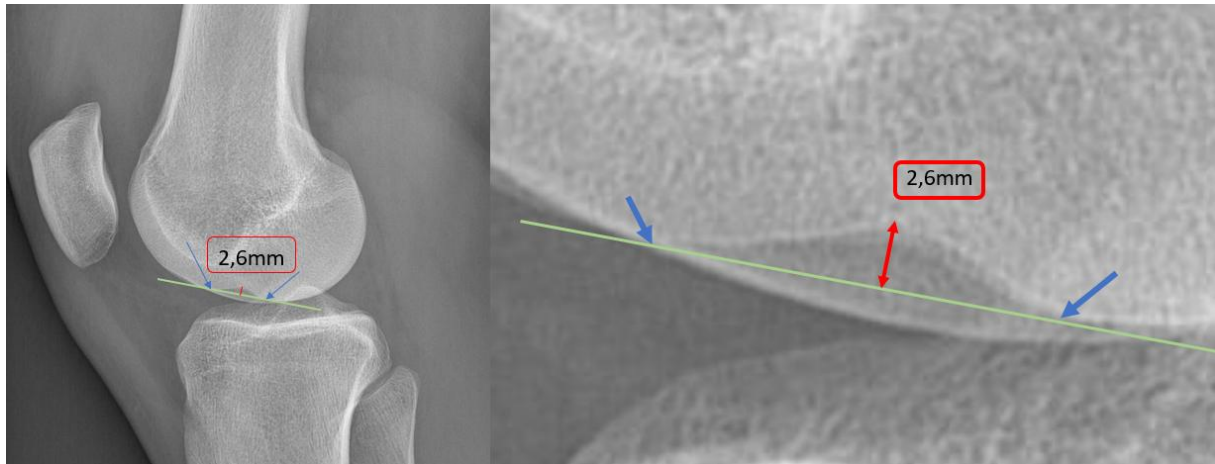


Image 1 : Measurement of the lateral femoral condylar notch depth on a right knee lateral radiograph

Statistical Analyses

Literature reports an approximate 50% prevalence of ACL rupture in acute knee trauma cases requiring MRI⁶. Therefore, for each case with an ACL rupture, a matched control without ACL rupture was included in the analysis.

Given a reported specificity of 98.1% for a lateral femoral notch depth threshold of 1 mm in the literature¹³, a sample size of 206 patients per group was required to assess specificity with a precision greater than 5%. Sample size calculations were performed using RStudio (version 2022.07.1) and the EpiR package (version 2023-01-15).

Descriptive statistics were used to summarize continuous and categorical variables, analyzed using Jamovi (version 2.3.21.0). Group comparisons were conducted using the chi-square test or Fisher's exact test for categorical variables, and the Student's t-test or Wilcoxon rank-sum test for continuous variables, as appropriate.

The diagnostic accuracy of LFNS depth in patients with anterior cruciate ligament (ACL) rupture was quantified by estimating the area under the receiver operating characteristic (AUROC) curve and its 95% confidence interval. Diagnostic properties were calculated at predefined thresholds (0.5 mm, 1 mm, 1.5 mm) based on literature data, using contingency tables.

Compliance with Ethical Standards

This was a non-interventional, retrospective study that did not meet the criteria for research involving human subjects as defined by the French legislation. After review by the Clinical Research and Innovation Department of our institution, the study received investigational authorization on July 10, 2023, and thus complies with the CNIL (French data protection authority) Reference Methodology MR-004. This retrospective study was approved by the Ethics Committee for Research at our university (CERGA-Avis-2023-27). The imaging data used were anonymized, in accordance with the Declaration of Helsinki and the GDPR. No individual consent was required due to the irreversible anonymization of the data.

Finally, the study was notified to the Data Protection Delegation of Grenoble Alpes University Hospital (CHUGA) and was registered in the Data Protection Officer's (DPO) processing activity log on October 11, 2023.

RESULTS

Population Characteristics (table 1)

A total of 412 patients were included: 206 cases with anterior cruciate ligament (ACL) rupture and 206 controls without ACL rupture following acute knee trauma. The case group was significantly younger (28.2 ± 10.4 years old) than the control group (30.7 ± 11.8 years old), and men were statistically overrepresented (74.8% and 62.6%) compared to women (25.2% and 37.4%) in case and control groups, respectively. Anthropometric characteristics (height and weight) were comparable between the two groups, and there was no significant difference in the laterality of the injured knee. Patients in the control group reported a higher incidence of previous meniscal injuries or spontaneously reduced patellar dislocation compared to the case group. High-risk pivot-contact sports were more frequently associated with trauma in the case group than in the control group (45.1% vs 24.2% ; $p\text{-value} < 0.01$) (Table 1).

	Case (n = 206)	Controls (n = 206)	p-value
Age (years)	28,2 (+/- 10.4)	30,7 (+/- 11.8)	0.024
Sex			
- Female	52 (25.2%)	77 (37.4%)	0.008
- Male	154 (74.8%)	129 (62.6%)	
Height (cm)	174 (+/- 9.13)	174 (+/- 9.37)	0.391
Weight (kg)	76 (+/- 15.6)	74,4 (+/- 15.5)	0.286
Injured Knee			
- Right	108 (52.4%)	104 (50.5%)	0.693
- Left	98 (47.6%)	102 (49.5%)	
Medical history			
- Peripheral ligament tear	2 (1%)	8 (3.9%)	0.055
- Meniscal disorder	1 (0,5%)	8 (3.9%)	0.018
- Patellar instability	0 (0%)	7 (3.4%)	0.008
Traumatic activity	See Diagram 1	See Diagram 2	
- Pivot contact / high-risk sports	93 (45.1%)	50 (24.2%)	< 0.01
- Pivot non-contact / low-risk sports	43 (20.9%)	30 (14.6%)	0.093
- Non-pivot sports	40 (19.4%)	41 (19.9%)	0.9
- Other	30 (14.6%)	85 (41.3%)	< 0.01
Initial diagnosis			
- ACL tear	158 (76.7%)	70 (34%)	
- Peripheral ligament sprain or sprain requiring reassessment	32 (15.5%) 9 (4.3%)	66 (32%) 46 (22.3%)	
- Meniscal syndrome	7 (3.4%)	24 (11.7%)	
- Other			

Table 1 : Characteristics of the population

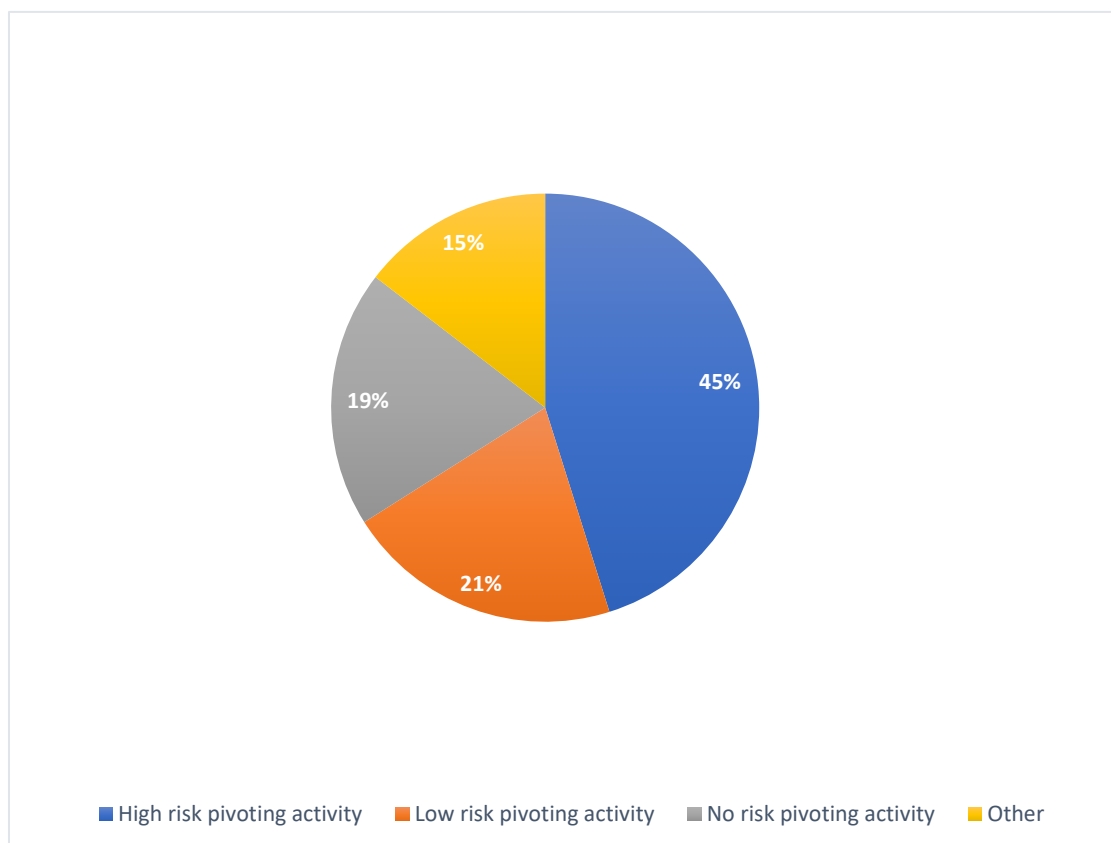


Diagram 1 : Traumatic events in the cases group

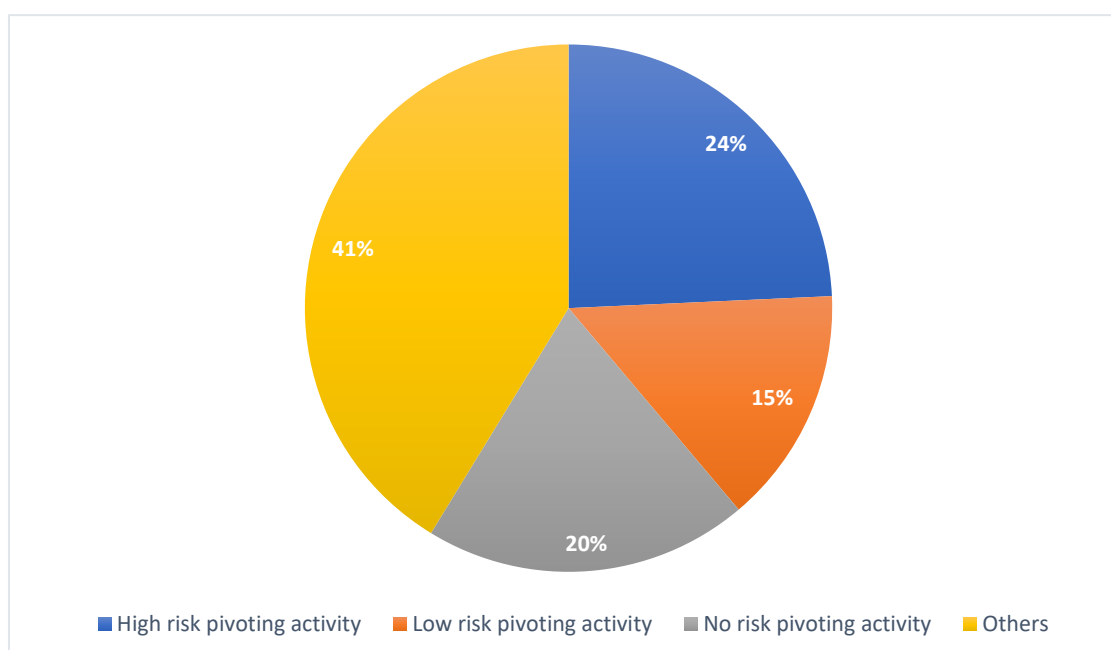


Diagram 2 : Traumatic events in the control group

Diagnostic Test Results

The lateral femoral notch depth was significantly greater in the case group (0.7 ± 0.6 mm) compared to the control group (0.2 ± 0.2 mm) across all tested thresholds (0.5 mm, 1 mm, 1.5 mm), with a p-value < 0.001 (Table 2).

Sensitivity, specificity, positive likelihood ratios (LR+), and negative likelihood ratios (LR-) for each threshold are presented in Table 3. At a 1 mm threshold, the specificity was 98.5%, sensitivity 31.1%, LR+ 21.3, and LR- 0.7.

	Case (n = 206)	Control (n = 206)	p-value
Depth of LFNS (mm)	0.677 (+/- 0.613)	0.214 (+/- 0.286)	< 0.001
- ≥ 0.5	127 (61.6%)	79 (38.3%)	< 0.001
- ≥ 1	64 (31.1%)	3 (1.5%)	< 0.001
- ≥ 1.5	23 (11.2%)	0 (0.0%)	< 0.001

Table 2 : Depth of the lateral femoral condylar notch and distribution of patients according to different thresholds

Threshold values	Se (%)	Sp (%)	PLR	NLR
≥ 0.5 mm	61.7 (54.6 – 68.3)	78.6 (72.4 – 84.0)	2.89 (2.17 – 3.8)	0.49 (0.40 – 0.59)
≥ 1 mm	31.1 (24.8 – 37.9)	98.5 (95.8 – 99.7)	21.3 (6.8 – 66.8)	0.7 (0.64 – 0.77)
≥ 1.5 mm	11.2 (7.2 – 54.9)	100 (98.2 – 100)		0.88 (0.85 – 0.93)

Table 3 : Diagnostic values for the lateral condylar notch based on the selected threshold

PLR : Positive Likelihood ratio ; NLR : Negative likelihood ratio

No statistically significant association was found between the presence of a lateral femoral notch sign (LFNS) ≥ 1 mm and concomitant injuries diagnosed by MRI (meniscal, cartilage, posterior cruciate ligament, or collateral ligament injuries) in the case group (Table 4).

	Notch < 1mm (N = 142)	Notch ≥ 1mm (N = 64)	p-value
MCL	54 (38%)	33 (51.6%)	0.069
LCL	28 (4%)	13 (6%)	0.921
PCL	6 (19.7%)	4 (20.3%)	0.531
MM	51 (35.9%)	21 (32.8%)	0.666
LM	36 (25.4%)	22 (34.4%)	0.183
Cartilage injury	39 (27.5%)	18 (28.1%)	0.922

Table 4 : Associated injuries in patients with ACL tears, based on the presence or absence of a meniscal tear ≥ 1 mm

MCL : medial collateral ligament ; LCL : lateral collateral ligament ; PCL : Posterior cruciate ligament ; MM : Medial meniscus ; LM : Lateral meniscus

Composite Criterion

The performance of a composite diagnostic criterion—including elements available during an emergency consultation for acute knee trauma—was also evaluated. The composite criterion was defined as a notch depth > 1 mm combined with the presence of clinical hemarthrosis (table 5). Sensitivity, specificity, PLR, and NLR are presented in table 6. Using this composite criterion, the discriminative performance achieved a specificity of 99.5% .

	Criterion + (Clinical + and notch ≥ 1 mm)	Criterion – (Clinical – and/or notch < 1 mm)	
Torn ACL	52	154	206
Intact ACL	1	205	206
	53	359	

Table 5 : Composite criterion contingency table

	Se (%)	Sp (%)	PLR	NLR
Composite criterion +	25 (19.5 – 31.7)	99.5 (97.3 – 100)	52 (7.26 – 372.6)	0.751 (0.694 – 0.814)

Table 6 : Diagnostic characteristics of the composite criterion

Se : sensitivity ; Sp : specificity ; PLR : Positive likelihood ratio ; NLR : negative likelihood ratio

DISCUSSION

The main finding of this study is the high clinical value of measuring LFNS depth in emergency settings for patients with acute knee trauma. This measurement is easy to learn and apply, and its diagnostic performance—particularly its 98.5% specificity for a notch depth > 1 mm—makes it a reliable confirmatory tool for diagnosing anterior cruciate ligament (ACL) ruptures. The methodology used to assess this radiographic sign can be implemented without disrupting patient management or incurring additional costs.

Strengths of the Study

Our study represents the largest series in the literature on this topic and is the only one with sufficient statistical power to define the intrinsic characteristics of this diagnostic test.

Comparison with the Literature

Our findings are consistent with current studies and reinforce the idea that the LFNS is a marker of ACL rupture. This study further establishes the LFNS as a valuable tool in the diagnostic arsenal for ACL injuries. Recent studies by Gong⁶, Lodewijks¹³, and Herbst³ also highlighted the association between ACL injuries and LFNS, though their reported notch depth thresholds varied: 0.72 mm⁶, 1 mm¹³, and 2 mm³. Our determined threshold aligns with the range observed in previous research.

In our study, the presence of an LFNS in ACL rupture cases did not predict associated peripheral injuries. This aspect distinguishes our findings from those of recent studies. For instance, Lodewijks¹³ and Herbst³ reported a statistically significant increase in lateral meniscal tears when a prominent lateral femoral notch was present. However, these studies were conducted with smaller patient cohorts, which may account for the discrepancy.

Limitations

Despite its high specificity, the sensitivity of this measurement remains limited. Therefore, the absence of this notch does not rule out an ACL injury in acute knee trauma, and further clinical reassessment remains essential.

Additionally, while measuring the notch is straightforward, its dimensions approach the millimeter-scale margin of error commonly accepted in musculoskeletal imaging. Some radiological software may not allow measurements smaller than 1 mm, although the use of digital radiography mitigates this issue. The clinical application of this radiographic sign thus requires strict adherence to quality criteria for knee radiographs as the barely deviation from perfect radiograph view jeopardize the measurement of the LFNS⁴. In a trauma setting, achieving these radiological standards can sometimes be challenging.

Our study benefits from being conducted in a specialized trauma emergency center, where skilled musculoskeletal radiology technicians ensure high-quality radiographs. This may not be universally replicable in all clinical settings.

Relevance of This Test

The notch depth thresholds studied (0.5 mm, 1 mm, and 1.5 mm) were empirically selected, based both on thresholds reported in previous studies and our clinical experience. As expected, the specificity of the LFNS increases progressively with higher depth thresholds. We chose the 1 mm threshold based on our initial hypothesis that the presence of LFNS would predict an anterior cruciate

ligament (ACL) rupture. Analysis of the area under curve (AUC) confirmed that this threshold provides the highest diagnostic specificity while remaining a relatively common finding (31.1% of patients with an ACL rupture had an LFNS ≥ 1 mm in our series). Additionally, 1 mm is widely considered the margin of error in musculoskeletal imaging, making sub-millimeter measurements impractical for routine clinical use.

The radiological analysis is quick and imposes no additional burden on the practitioner once the measurement technique is mastered. Any trained physician can measure this notch. In a 2019 study, measurements were performed by two radiologists, an orthopedic surgeon, and a sports medicine physician². The authors demonstrated inter-observer reproducibility of 93% and intra-observer reproducibility of 96% for LFNS measurement, reinforcing the reliability of this sign².

With the current rise of artificial intelligence (AI) software applied to medical imaging⁵ and its increasing use in emergency departments, we can envision the systematic measurement of lateral femoral notch depth on all lateral knee radiographs of patients presenting with recent trauma. Clinicians would then have real-time access to this information.

CONCLUSION

Measuring the LFNS in acute knee trauma allows clinicians to confirm an ACL rupture with 98.5% specificity when the notch depth exceeds 1 mm, and 99.5% specificity when combined with clinical hemarthrosis. However, due to its low sensitivity, the absence of LFNS cannot rule out an ACL injury

AUTHOR CONTRIBUTION

GPS conceived the study, collected the data together with SD, performed the data analysis, and prepared the original draft of the manuscript. PG, CH, VM, and CR critically reviewed and revised the manuscript. JJB supervised the project. All authors read and approved the final manuscript.

FUNDING DECLARATION

The authors declare that no funding was received for this study.

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