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The deep lateral femoral notch sign: a reliable diagnostic tool in identifying a concomitant anterior cruciate and anterolateral ligament injury

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Abstract

Purpose The aim of the present study was to investigate the validity and reliability of the deep lateral femoral notch sign (DLFNS) in identifying a concomitant anterior cruciate ligament (ACL)/anterolateral ligament (ALL) rupture and predicting the clinical outcomes following an anatomical single-bundle ACL reconstruction. It was hypothesized that patients with a concomitant ACL/ALL rupture would have an increased DLFNS compared to patients without a concomitant ACL/ALL rupture.

Methods The lateral preoperative radiographs and MRI images of 100 patients with an ACL rupture and 100 control subjects were evaluated for the presence of a DLFNS and ACL/ALL rupture, respectively. The patients were evaluated clinically preoperatively and at a minimum 1 year following the ACL reconstruction. A receiver operator curve (ROC) analysis was performed to define the optimal cut-off value of the DLFNS for identifying a concomitant ACL/ALL injury. The relative risk (RR) was also calculated to determine whether the presence of the DLFNS was a risk factor for residual instability or ACL graft rupture following an ACL reconstruction.

Results The prevalence of DLFNS was 52% in the ACL-ruptured patients and 15% in the control group. At a minimum 1-year follow-up, 35% (6/17) of the patients with DLFNS > 1.8 mm complained of persistent instability, and an MRI evaluation demonstrated a graft re-rupture rate of 12% (2/17). In patients with a DLFNS < 1.8 mm, 8% (7/83) reported a residual instability, and the graft rupture rate was 2.4% (2/83). A DLFNS > 1.8 mm demonstrated a sensitivity of 89%, a specificity of 95%, a negative predictive value of 98%, and a positive predictive value of 89% in identifying a concomitant ACL/ALL rupture. Patients with a DLFNS > 1.8 mm had 4.2 times increased risk for residual instability and graft rupture compared to patients with a DLFNS ≤ 1.8 mm.

Conclusions A DLFNS > 1.8 mm could be a clinically relevant diagnostic tool for identifying a concomitant ACL/ALL rupture with high sensitivity and PPV. Patients with a DLFNS > 1.8 mm should be carefully evaluated for clinical and radiological signs of a concomitant ACL/ALL rupture and treated when needed with a combined intra-articular ACL reconstruction and extra-articular tenodesis to avoid a residual rotational instability and ACL graft rupture.

Level of evidence III.

Keywords Anterior cruciate ligament · Anterolateral ligament · Deep lateral femoral notch sign · Radiograph · Clinical outcomes

Introduction

Anterior cruciate ligament (ACL) rupture is one of the most common sports injuries among young athletes [14, 18, 25]. Despite the significant advancement in ACL-reconstruction surgery, the current evidence suggests that up to 30% of the patients complain of persistent instability [6, 11] and impaired quality of life [5], following an ACL reconstruction. 65% of

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ACL-reconstructed male athletes can return to top-level 3 years after ACL rupture [31]. However, regarding professional athletes, recent studies reported that only 55% could return to their preinjury level, following a primary [1] and 47.6% following a revision ACL reconstruction [8]. A potential reason for the residual rotational instability and poor outcomes might be a concomitant rupture to the anterolateral ligament (ALL) of the knee, as several studies confirmed the contributing role of the ALL in controlling the excessive tibial internal rotation in the absence of the ACL [20, 27]. The latest recommendations for a combined ACL/ALL reconstruction include young (age < 25 years), highly active patients (pivoting sports), a pivot-shift test Grade II–III, Lachman test > 7 mm, Segond fracture, ACL revision, and a positive deep lateral femoral notch sign (DLFNS) [27].

Although the recommendations mentioned above appear straightforward, the clinical and radiological diagnosis of a concomitant ACL/ALL rupture remains challenging, especially in the acute setting. Several studies demonstrated only moderate reliability of the ACL clinical examination with inter-observer reliability of 0.57 for the Lachman test and 0.53 for the pivot-shift test [24]. Notably, in the emergency department, a substantial proportion of acute ACL ruptures (as high as 75%) are not diagnosed [9]. Even with a high-quality 3-Tesla magnetic resonance imaging (3T MRI), the diagnosis of an ALL rupture in the setting of concomitant ACL rupture has poor inter-observer reliability due to the lack of entire visualization of the ALL in about 79–89% of the patients [3, 15]. Therefore, a reliable screening tool might be necessary, as an adjunct to the clinical and radiological examination, in identifying a concomitant ACL/ALL rupture.

The DLFNS on the conventional radiographs has been described as a simple and reliable screening tool for the diagnosis of the ACL rupture in the acute setting [13]. Nevertheless, the role of the DLFNS in predicting a concomitant ACL/ALL rupture has never been reported in the literature. Therefore, the aim of the present study was to investigate the validity and reliability of the DLFNS in identifying a concomitant ACL/ALL rupture and predicting residual instability and graft rupture following an anatomical single-bundle ACL reconstruction. It was hypothesized that patients with a concomitant ACL/ALL rupture would have an increased DLFNS compared to patients without a concomitant ACL/ALL rupture. The present study might help surgeons to identify a concomitant ACL/ALL rupture through the measurement of DLFNS.

Materials and methods

The present single-center, retrospective study was approved by the authors' institutional Internal Review Board and the ethical committee (Ethical Committee Northeast and Central Switzerland 2018-01410). Following informed consent, the medical records and MRIs of patients presented in our emergency department following an acute, non-contact knee injury from 2014 to 2017 were retrospectively reviewed. Exclusion criteria were age > 40 years, history of patellofemoral instability, previous surgery or symptoms in the affected knee, posterior tibia slope > 7° [29, 30], clinically excessive varus/valgus leg axis, and Segond fracture (as these patients were treated with a combined intra-articular ACL areconstruction and extra-articular tenodesis). Inclusion criteria in the ACL-ruptured group were: ACL rupture confirmed arthroscopically, and a 1-year minimum follow-up after a single-bundle ACL reconstruction. The ACL-ruptured patients were randomly matched for gender, age, and body mass index (BMI) with patients without an ACL rupture (control group), but a bone bruise of the distal femur or proximal tibia on MRI, suggesting a significant knee injury.

A total of 100 patients with an ACL rupture and 100 randomly selected, matched-controlled subjects were identified (Tables 1 and 2). All the patients in the ACL-ruptured group underwent knee arthroscopy and anatomical single-bundle reconstruction, whereas, in the control group, only patients with a meniscus lesion (36%) underwent knee arthroscopy and meniscus repair.

Radiological measurements

The digital lateral radiograph of the knee was performed at the initial presentation at the emergency department, following a standardized protocol, with the patient supine on the table, the knee slightly flexed at 30° and parallel to the radiograph device, using equal magnification factors. If the medial and lateral femoral condyles did not show a maximum overlap (Fig. 1), the radiograph was repeated. The depth of the DLFNS was defined as the distance between a tangent line on the articular surface of the lateral femoral condyle and the deepest point of the DLFNS (Fig. 1a) [13]. The location of the DLFNS was determined by an imaginary clock centered on the cylindrical axis [21] of the knee and the 12 o'clock axis aligned with the Blumensaat line (Fig. 1b). A DLFNS ≥ 0.5 mm was considered as a positive DLFNS (Fig. 1c), based on the study of Cobby et al. [2], which reported that patients with an intact ACL demonstrated an average depth of 0.5 mm.

MRI characteristics and image processing

All the patients were scanned using a 3.0-Tesla MR Scanner (Achieva, Philips Healthcare, The Netherlands) within 1 month of injury. The PDW TSE SPAIR sagittal-plane images and T1 HR TSE coronal-plane images were obtained. The two MR image stacks were combined to yield volumetric data with a voxel size of 0.22 by 0.25 by 0.24 mm

Table 1 Patient characteristics and concomitant injuries. The values are given in average value and range

Parameter	ACL-ruptured group ($n = 100$)	Control group ($n = 100$)	Significance (p value)
Age (years)	26 (16–39)	26 (16–38)	n.s.
Gender (male, female)	55, 45	52, 48	n.s.
BMI (kg/m^2)	22.2 (18.1–26.9)	22.4 (18.2–27.4)	n.s.
Concomitant injuries			
Medial meniscus (n)	21%	23%	
Lateral meniscus (n)	17%	13%	
Lateral collateral ligament (n)	5%	4%	
Medial collateral ligament (n)	1%	3%	
Isolated bone bruise	42%	57%	
ALL rupture	17%	0	

No significant difference was identified in age, gender, and BMI between ACL-ruptured and control groups

ACL anterior cruciate ligament, *ALL* anterolateral ligament, *BMI* body mass index

Table 2 Patient characteristics and concomitant injuries divided according to the DLFNS depth

Injuries	No DLFNS ($n = 133$)	DLFNS < 0.9 mm ($n = 7$)	1.8 ≥ DLFNS ≥ 0.9 mm ($n = 43$)	DLFNS > 1.8 mm ($n = 17$)
ACL without ALL rupture ($n = 83$)	48/133 (36%)	0	34/43 (79%)	1/17 (6%)
Concomitant ACL/ALL rupture ($n = 17$)	0	0	1/43 (6%)	16/17 (94%)
Control group ($n = 100$)	86/133 (65%)	7/7 (100%)	7/43 (23%)	0
Medial meniscus ($n = 44$)	20/133 (15%)	3/7 (42%)	16/43 (37%)	5/17 (30%)
Lateral meniscus ($n = 30$)	11/133 (14%)	2/7 (29%)	3/43 (7%)	14/17 (82%)
Lateral collateral ligament ($n = 9$)	3/133 (2.2%)	1/7 (14%)	1/43 (2%)	4/17 (23%)
Medial collateral ligament ($n = 4$)	2/133 (2%)	1/7 (14%)	0	1/17 (6%)
ITB/anterolateral capsule ($n = 5$)	0	0	0	5/17 (30%)
Popliteus tendon ($n = 3$)	0	0	0	3/17 (18%)

The values are given in frequencies and percentages

DLFNS deep lateral femoral notch sign, *ACL* anterior cruciate ligament, *ALL* anterolateral ligament, *ITB* iliotibial band

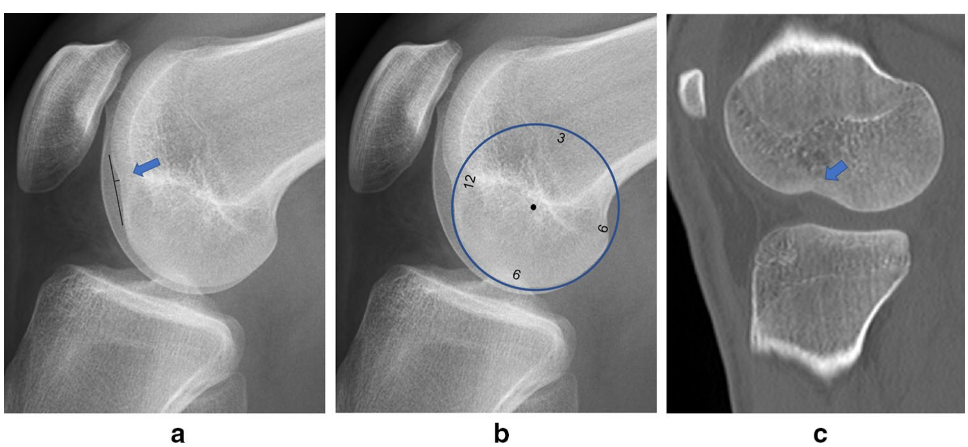


Fig. 1 **a** An example of a right knee radiograph demonstrating a DLFNS > 1.8 mm. The current patient suffered a concomitant ACL/ALL rupture. The depth of the DLFNS was defined as the distance between a tangent line at the articular surface of the lateral femoral condyle and the deepest point of the DLFNS [13]. **b** The DLFNS location was determined by an imaginary clock centered on the cylindrical axis of the knee and the 12 o'clock axis aligned on the Blumensaat line. **c** A CT of the same patient showing the DLFNS. *ACL* anterior cruciate ligament, *ALL* anterolateral ligament, *DLFNS* deep lateral femoral notch sign

(Fig. 2a) using commercial software (AMIRA 6.5, FEI SVG, Thermo Fisher Scientific, Hillsboro, Oregon, USA) (Fig. 1). The ALL was identified according to the recommendations suggested by Patel et al. [21]. (Fig. 2a). An ALL rupture was diagnosed on MRI according to Muramatsu et al.'s [19] recommendations as warping, thinning, iso-signal changes of the ALL, or loss of continuity (Fig. 2b).

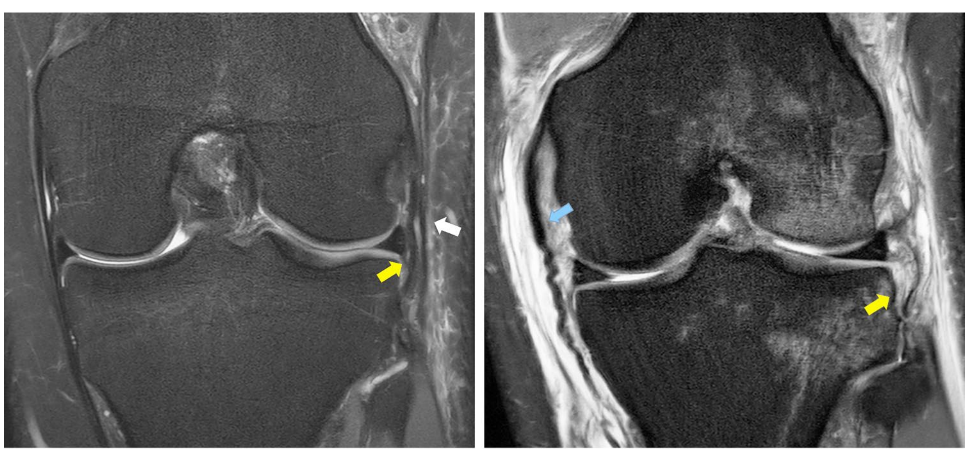
Clinical evaluation

Following the lateral knee radiograph and MRI, all the patients were evaluated in our outpatient clinic at an average of 4.2 ± 1.3 weeks following the injury. A radiologist evaluated the MRI, whereas an orthopedic surgeon evaluated the patients clinically. An ACL rupture was confirmed clinically by a positive Lachman and anterior drawer test [7, 12], whereas an ALL rupture was confirmed clinically with a positive pivot-shift test. The diagnosis of an ALL rupture was confirmed upon agreement of both clinical and MRI findings. If there was a discrepancy between the clinical and MRI findings, the patients were excluded from the study. Patients in both groups who underwent knee arthroscopy and ACL reconstruction and/or meniscus repair were followed up clinically at 6 weeks, 3 months, 6 months, and 1 year postoperatively, and then as required.

Surgical technique and rehabilitation protocol

All the patients with an ACL rupture underwent an anatomical single-bundle ACL reconstruction with a four-strand autologous semitendinosus tendon. The graft was fixed with an EndoButton CL (Smith and Nephew, Andover, MA) at the femoral site and with an interference screw (Arthrex, Naples, Florida, USA) at the tibial site. Regarding the treatment of meniscus injuries, 6 medial menisci and 4 lateral menisci were partially removed, and 19 medial menisci and 9 lateral menisci were repaired in the ACL-ruptured group, whereas 8 medial menisci and 7 lateral menisci were partially removed, and 11 medial menisci and 10 lateral menisci were repaired in the control group.

Knee range-of-motion exercises were started immediately postoperatively, whereas weight-bearing started 2 days postoperatively with two crutches. Full weight-bearing walking was allowed 2 weeks postoperatively in patients without meniscus repair with an instructed range-of-motion with 90°/0°/0° for 2 weeks and 110°/0°/0° thereafter. Patients with a meniscus repair were instructed to partial weight-bearing of 15 kg for 6 weeks, and the range-of-motion was 30°/0°/0° for 2 weeks, 60°/0°/0° for the following 2 weeks and 90°/0°/0° thereafter, in a hinged ROM knee brace. Full recovery of knee motion was expected 3 months after surgery. Knee muscle exercise was encouraged starting 6 weeks after surgery in the closed kinetic fashion. Running exercise was started at 3 months, first as jogging, and then, the running speed was gradually increased. When 80% of the full-speed running was achieved, athletic exercises related to the previous sports or desired sporting activities were initiated with detailed instructions. Full athletic activities were allowed at 6 months following surgery.



a b

Fig. 2 **a** A coronal MRI of a patient with an intact ALL (yellow arrow). The LCL is demonstrated with a white arrow. According to Patel et al. [21], the origin of the ALL was identified in the coronal and axial planes just anterior and distal to the lateral collateral ligament and the ALL bifurcation to its tibial and meniscal insertions, medial to the lateral geniculate artery. The ALL follows an antero-inferior direction to its tibial insertion at approximately 5 mm distal to the lateral tibial plateau midway between the lateral collateral ligament and iliotibial band. **b** An MRI of a patient with an ALL rupture (yellow arrow). The patient had the characteristic bone bruise on the lateral femoral condyle and posterolateral tibial plateau. This patient also suffered an MCL rupture (blue arrow). *ACL* anterior cruciate ligament, *ALL* anterolateral ligament, *LCL* lateral collateral ligament, *MCL* medial collateral ligament

Repeatability analysis

Two independent blinded observers (M.R. and D.D) evaluated the depth of the DLFNS and its location relative to the Blumensaat line. Then each observer re-assessed all the radiographs at a 4-week interval to avoid recall bias. The intra-observer and inter-observer reliabilities of the measurements were evaluated using a single-measure intraclass correlation coefficient (ICC) with a two-way random-effects model for absolute agreement. The intra-observer and inter-observer reliability was in absolute agreement for the DLFNS depth (0.94 and 0.91) and location (0.91 and 0.89), respectively. The agreement between the pivot-shift test and complete ACL/ALL rupture in the MRI was 85% (17/20 patients). The remaining three patients did not demonstrate a pivot-shit test, but the ALL could not be identified on the MRI, and, therefore, were excluded from the study.

Statistical analysis

Descriptive statistics used standard deviation and range to describe all the continuous variables, whereas frequencies and percentages were used to present the discrete variables. A receiver-operating characteristic (ROC) curve analysis was performed to define the optimal cut-off value of the DLFNS in detecting an ACL- and a concomitant ACL/ALL rupture. The Youden index [16] was utilized to determine the ideal cut-off value with the highest sensitivity and specificity. Based on the calculated cut-off value, the sensitivity, specificity, negative predictive value, and positive predictive value of the DLFNS were calculated. The relative risk (RR) was also calculated to determine whether the presence of the DLFNS was a risk factor for residual instability or graft rupture. Sample size calculation under the ROC curve area was performed with significance level $\alpha = 0.05$, power level $\beta = 0.95$, AUC = 0.92, null hypothesis value = 0.5, and the ratio of sample sizes in negative/positive groups = 10. The result shows that the total sample size required larger than 55, while positive cases require 5 and negative cases require 50 [10]. All the statistical analyses were performed using SPSS version 23 software (SPSS Inc., Chicago, Illinois).

Results

Radiologic evaluation

In the ACL-ruptured group, 52% of the patients demonstrated a positive DLFNS (> 0.5 mm) with an average depth of 1.8 ± 0.7 mm. The DLFNS was located at 11 o'clock in 55%, at 12 o'clock at 33%, and 1 o'clock in 12% of the patients with a positive sign. In the control group, 15% of the patients demonstrated a DLFNS with an average depth of 0.8 ± 0.3 mm ($p < 0.01$). The DLFNS was located at 11 o'clock in 60%, at 12 o'clock at 27%, and 1 o'clock in 13% of the patients with a positive sign. In patients with a concomitant ACL/ALL rupture, the DLFNS had an average depth of 2.7 ± 0.5 mm ($p < 0.01$), and it was located at 11 o'clock in 87% of the patients with a positive sign.

ROC curve analysis and characteristics of the DLFNS on a lateral knee radiograph

The ROC curve analysis demonstrated that a cut-off of 0.9 mm for the DLFNS yielded a sensitivity of 51% and specificity of 99% for predicting an ACL rupture in the present cohort [area under the curve (AUC) = 73%]. The positive and negative predictive values of the DLFNS > 0.9 mm for predicting an ACL rupture were 98% and 64%, respectively. A cut-off of 1.8 mm for the DLFNS yielded a sensitivity of 89% and specificity of 95% for predicting a concomitant ACL/ALL rupture in the present cohort (area under the curve (AUC) = 92%) (Fig. 3). The positive and negative predictive values of the DLFNS > 1.8 mm for predicting a concomitant ACL/ ALL rupture were 89% and 98%, respectively.

Clinical follow-up

At a minimum 1-year follow-up, 35% (6/17) of the patients with DLFNS > 1.8 mm complained of persistent instability, which affected their ability to return to sports. The clinical examination and subsequent MRI demonstrated a graft re-rupture rate of 12% (2/17) of the patients. The remaining four patients had a negative Lachman test, but demonstrated a residual pivot-shift. On the contrary, in patients with a DLFNS < 1.8 mm, only 8% (7/83) reported a residual instability also confirmed clinically with a positive pivot-shift test. The graft rupture rate was 2.4% (2/83). Patients with an ACL graft rupture were treated with a modified Lemaire lateral tenodesis [23] accompanied by an intra-articular ACL reconstruction, whereas patients with residual instability without an ACL graft rupture, with intensive physiotherapy. A DLFNS > 1.8 mm was significantly associated with a higher risk for residual instability or ACL graft rupture (RR = 4.2; 95% CI = 1.6–11.1, $p < 0.01$) compared to patients with a DLFNS ≤ 1.8 mm, at a minimum 1-year following an anatomical single-bundle ACL reconstruction.

Discussion

The most important finding of the present study was that a DLFNS > 1.8 mm might be a clinically relevant tool for identifying a concomitant ACL/ALL rupture with a sensitivity of 89%, a specificity of 95%, a negative predictive value

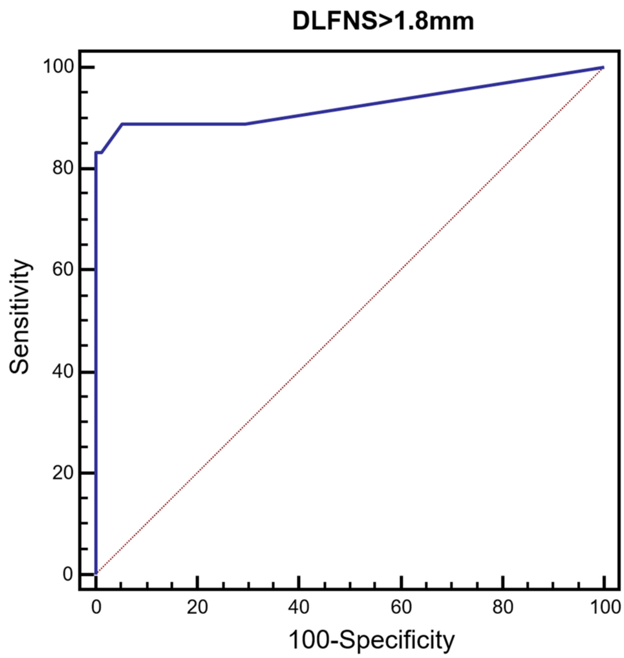


Fig. 3 An ROC curve analysis was performed to determine the optimal cut-off value of the DLFNS, for detecting a concomitant ACL/ALL rupture. A cut-off of 1.8 mm for the DLFNS yielded a sensitivity of 89% and specificity of 95% for predicting a concomitant ACL/ALL rupture in the present cohort (AUC = 92%). *ACL* anterior cruciate ligament, *ALL* anterolateral ligament, *AUC* area under the curve, *DLFNS* deep lateral femoral notch sign

of 98%, and a positive predictive value of 89%. Patients with a DLFNS > 1.8 mm had 4.2 times increased risk for residual instability and ACL graft rupture compared to patients with a DLFNS ≤ 1.8 mm, at a minimum 1 year following an anatomical single-bundle ACL reconstruction.

Recently, Lodewiks et al. [13] investigated the validity and inter- and intra-observer reliability of the DLFNS in diagnosing an acute ACL rupture in 65 patients with an ACL rupture and 53 control subjects. They concluded that a DLFNS > 1 mm had a very high PPV (96%) for an acute ACL rupture with an inter- and intra-observer reliability of 0.93 and 0.96, respectively. In the present study, in accordance with the Lodewiks et al.'s findings, a high inter-, intra-observer reliability, and PPV (98%) were found regarding the depth of the DLFNS. Additionally, a DLFNS > 1.8 mm demonstrated very high test characteristics (sensitivity: 89%, specificity: 95%, negative predictive value: 98%, and positive predictive value: 89%) for identifying a concomitant ACL/ALL rupture. The results of the present study might suggest that a DLFNS > 1.8 mm could be a clinically relevant diagnostic tool for identifying a concomitant ACL/ALL rupture.

The large external forces responsible for ACL rupture might cause a violent impact between the tibia and femur, which results in a bone bruise identified on MRI [22, 28]. Disruption of the ACL may result in an abnormal anterior tibial translation relative to the femur, causing a forceful impaction of the lateral femoral condyle on the posterolateral tibial, resulting in the DLFNS [26] (Fig. 4). Filardo et al. [4], in a recent metanalysis, reported that the presence of subchondral fractures and the location of the bone bruise (lateral distribution correlated with a higher instability and ROM limitation, whereas medial distribution with higher pain) might negatively influence the clinical outcome and return to full activity following an ACL reconstruction. In the present study, patients with a DLFNS > 1.8 mm had 4.2 times increased risk for residual instability or ACL graft rupture compared to patients with a DLFNS ≤ 1.8 mm, at a minimum 1 year following a single-bundle reconstruction. This might be attributed to an undiagnosed concomitant ALL rupture, which was not addressed by an isolated anatomical single-bundle ACL reconstruction. Therefore, patients with a DLFNS > 1.8 mm should be evaluated carefully for clinical and radiologic signs of a concomitant ACL/ALL, and treated when needed with a combined intra-articular ACL reconstruction and extra-articular tenodesis to avoid a residual rotational instability and ACL graft rupture.

The current study should be interpreted in light of its potential limitations. The main drawback was the retrospective design. However, due to the standardized clinical and radiological follow-up protocol and the excellent documentation through the orthopedic surgeons of our institution, most of the patient data which we needed were available for the current analysis. In the present study, all the patients were scanned with a 3.0 Tesla MR Scanner, and two MR image stacks were combined to yield very high-quality MR images. In the clinical setting, with lower quality MR images, the identification of an ALL rupture might be technically challenging. Furthermore, it should be noted that there is no gold standard in the diagnosis of a concomitant ACL/ALL injury, and MRI abnormalities in the ALL/lateral capsule might be observed in as high as 84.6% of patients with an ACL rupture [17]. Therefore, in the present study, we included only patients with an MRI and clinical diagnosis (pivot-shift grade II–III) of an ACL/ALL rupture as the gold standard. Finally, in the present study, only lateral radiographs with maximal overlap between the medial and lateral femoral condyle were used to measure the DLFNS. Caution should be excised when the overlap of the femoral condyle is not optimal, as the rotation of the femur could affect the DLFNS measurement.

Conclusion

The present study is the only available in the literature investigating the validity and reliability of the DLFNS in detecting a concomitant ACL/ALL rupture in the acute setting. A

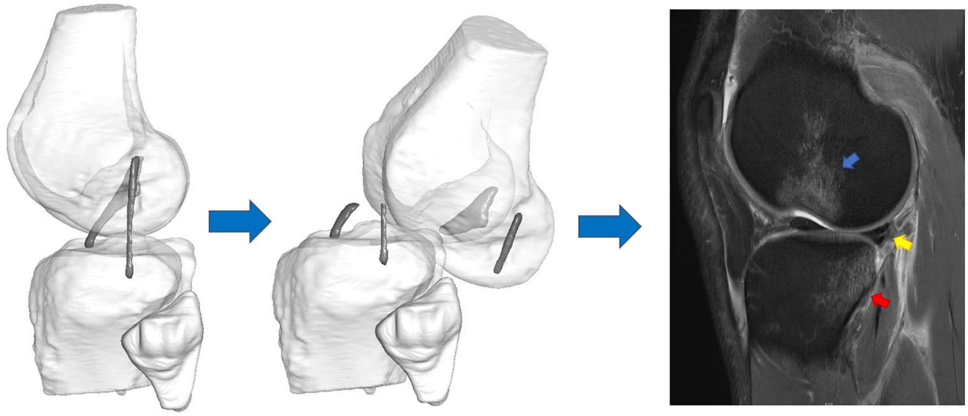


Fig. 4 A schematic illustration demonstrating the rupture mechanism resulting in the formation of the DLFNS and concomitant ACL/ALL rupture. Disruption of the ACL may result in an abnormal anterior tibial translation relative to the femur causing a forceful impaction of the lateral femoral condyle on the posterolateral tibial, resulting in the DLFNS and the characteristic bone bruises on the lateral femoral condyle around the DLFNS (blue arrow), the posterolateral tibia (red arrow), and injuries to the posterior horn of the lateral meniscus (yellow arrow). *ACL* anterior cruciate ligament, *ALL* anterolateral ligament, *AUC* area under the curve, DLFNS: deep lateral femoral notch sign

DLFNS > 1.8 mm might be a clinically relevant tool for detecting a concomitant ACL/ALL rupture with high sensitivity and PPV. The results of the present study suggest that patients with a DLFNS > 1.8 mm should be evaluated carefully for clinical and radiological signs of a concomitant ACL/ALL and treated when needed with a combined intra-articular ACL reconstruction and extra-articular tenodesis to avoid a residual rotational instability and ACL graft rupture.

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Compliance with ethical standards

Conflict of interest The authors of this manuscript have nothing to disclose that would bias our work.

Ethical approval The present single-center, retrospective study was approved by the authors' institutional Internal Review Board and the ethical committee (Ethical Committee Northeast and Central Switzerland 2018-01410).

IRB approval Ethikkommission Nordwest-und Zentralschweiz: 2018-01410.

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