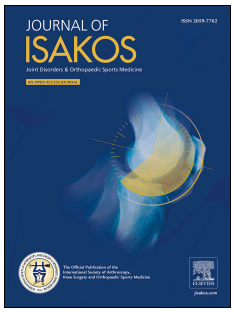

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The Lateral Femoral Notch Sign Decreases in Pediatric Patients Following Anterior Cruciate Ligament Reconstruction

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ABSTRACT

Introduction:

Anterior cruciate ligament (ACL) ruptures are common amongst pediatric patients, especially those participating in competitive sports. While magnetic resonance imaging (MRI) is typically used to confirm the diagnosis, certain radiologic findings can be indicative of an ACL tear, including a lateral femoral notch sign (LFNS) >1.5 millimeters (mm). No study has focused on understanding the resolution pattern of the LFNS in pediatric patients following ACL reconstruction (ACLR). The aim of this study is to determine whether the depth of the LFNS regresses following ACLR. The authors hypothesize that following ACLR, the LFNS will resolve.

Methods:

All patients who were treated for acute ACL rupture by one of two pediatric orthopedic surgeons between 2015 and 2020 were collected. 321 patients the ages of 5 to 18 were collected. Patients were excluded if they underwent previous ipsilateral knee surgeries and if they did not have pre-operative knee radiographs. 274 patients met inclusion criteria. LFNS was measured on pre-operative (PreOp) and most recent post-operative (PostOp) radiographs. A comparison cohort of patients with a LFNS <1.5mm matched by age within 1.5 years, sex, and laterality was also collected. The median difference was calculated by taking the difference between PreOp LFNS and PostOp LFNS of each participant and finding the median of those values.

Results:

274 pre-operative radiographs were analyzed for a LFNS depth >1.5mm. 17 radiographs met these criteria with a median age of 16.3 years and a median depth of 1.70mm. Of the 17 radiographs, 8 (47.1%) of participants were skeletally immature. The median LFNS depth at most recent follow up and median percent decrease were 1.50 mm and 28%, respectively. Only 11.8% of patients demonstrated no change in LFNS depth from PreOp to PostOp imaging. Wilcoxon Signed-Ranks test indicated that the PreOp LFNS was significantly greater than the PostOp LFNS ($p<0.001$). Mann Whitney U tests with cases and the comparison cohort demonstrated no difference in the percent decrease ($p=0.106$).

Conclusion:

This study sought to understand the resolution of the LFNS depth following initial ACL rupture. At a median of 7.67 months following ACLR, the LFNS depth decreased significantly by 0.60mm. These findings suggest that following ACL rupture, the pediatric LFNS has the potential to resolve. Future studies should aim to further assess the resolution pattern of the LFNS with advanced imaging, such as MRI.

What are the new findings?

- Following ACL rupture, the pediatric LFNS has the potential to resolve
- The LFNS had decreased significantly by 28% at approximately 8 months
- Intraoperative intervention for LFC depression is not necessarily required

Introduction:

Anterior cruciate ligament (ACL) ruptures have been increasing in the pediatric population,[1–3] accounting for approximately 30% of all knee injuries.[4,5] When diagnosing these ruptures, patients typically undergo both radiographic imaging and magnetic resonance imaging (MRI) of their knee. While MRI allows for visualization of the ACL itself, Segond fractures and a lateral femoral notch sign (LFNS) have been noted to suggest ACL rupture on radiographs.[6–12]

The LFNS is thought to occur due to impaction of the posterior tibia onto the lateral femoral condyle during anterior translation of the tibia at the time of the pivot shift when the ACL rupture occurs.[13,14] Various studies have sought to understand the incidence and typical depth of the LFNS sign[8–10,15–17], however, few studies have focused on the resolution pattern of the LFNS. Wierer et al. analyzed the LFNS following surgery using MRI in the adult population and found that the LFNS depth did not decrease but the total area of the notch did.[18]

To the authors knowledge, no study has focused on determining the resolution pattern of the LFNS in the pediatric population. This study sought to understand the progression of the LFNS in pediatric patients who suffered acute ACL rupture. We hypothesize that the depth of the LFNS will decrease significantly following ACL reconstruction in the pediatric population.

Methods:

Subjects:

After Institutional Review Board approval, patients 5 to 18 years old at initial visit seen by either of two pediatric orthopedic surgeons with the Current Procedural Terminology code 29888 (arthroscopically aided anterior cruciate ligament repair/augmentation or reconstruction) for acute ACL rupture between January 1st, 2016 and June 20th, 2020 were identified. 321 patients met these inclusion

criteria. Patients were excluded if they had undergone previous ipsilateral knee surgeries or if they did not have any pre-operative lateral knee radiographs. A total of 274 patients met these inclusion and exclusion criteria.

Comparison Cohort:

A comparison cohort of patients meeting inclusion and exclusion criteria with a LFNS depth of less than 1.5 millimeters (mm) were collected. This cohort was matched by sex, laterality, and age at surgery within 1.5 years with cases who had a LFNS greater than 1.5 mm.

Measurements:

Two blinded observers analyzed pre-operative and post-operative knee radiographs using Spectra IDS7 version 23.1 (Linköping, Sweden). Using the method described by Cobby et al, the LFNS depth was measured using a standard lateral knee radiograph.[19] This involved drawing a tangential line across the lower surface of the lateral femoral condyle to use as a reference line and measuring the depth of the notch perpendicular to the reference line (Figure 1).

Statistical Analysis:

Demographic information including sex, age at imaging, laterality, race, and ethnicity were collected. LFNS depth was measured for all lateral knee radiographs at initial presentation (PreOp) and most recent follow up (PostOp). Inter-rater reliability on a random sample of 10 participants was performed and demonstrated excellent reliability (ICC = 0.979). Depth difference was defined as PreOp depth minus PostOp depth. Due to the abnormal distribution in the Shapiro Wilks testing, medians were used. The median difference was calculated by taking the difference between PreOp LFNS and PostOp LFNS of each individual participant and finding the median of those values. Descriptive statistics, including medians and interquartile ranges (IQR), were calculated for all variables. Due to the sample size, Wilcoxon Signed-Rank test was used to compare LFNS depth at PreOp versus PostOp. Mann-

Whitney U tests were used to compare cases with the comparison cohort. Statistical significance was set at $p \leq 0.05$. IBM SPSS Statistics version 22 for Windows was used for all statistical analysis.

Results:

Pre-operative lateral radiographs of 274 patients who underwent ACL reconstruction were analyzed. 17 (5.8%) had a LFNS depth greater than 1.5 mm. Of the 17 radiographs, 8 (47.1%) of participants were skeletally immature. These patients had a median age of 16.3 (IQR = 14.9 – 17.1) years at time of surgery, with 52.9% being female (Table 1). 64.7% identified as White, while 72.4% identified as not Hispanic. 58.8% underwent surgery on their left ACL.

Median LFNS depth at time of presentation was 1.70 mm (IQR = 1.55 – 2.05). PostOp radiographs were performed at a mean 7.7 (IQR = 2.1- 19.2) months after surgery and found to have a mean LFNS depth of 1.50 mm (IQR = 1.00 – 1.60). This decrease correlated with a median depth decrease of 28% (IQR = 18.9 – 35.9) between PreOp and PostOp. PreOp LFNS depth was found to decrease in 88.2% patients, while 2/17 patients saw no change at their most recent radiograph. The median Depth difference was found to be 0.60 mm (IQR = 0.25 – 0.70). Wilcoxon Signed Rank Test indicated that PreOp LFNS (mean rank = 8.00) was significantly greater than PostOp LFNS (mean rank = 0.00) ($p < 0.001$).

A total of 13 cases were matched with the comparison cohort. The comparison cohort had a median pre-operative LFNS depth of 0.69 mm (IQR = 0.20 – 0.86). Postop radiographs at 9.67 months (IQR = 1.47 – 19.6) demonstrated a Postop LFNS depth of 0.48 mm (IQR = 0.075 – 0.89). This decrease was not determined to be statistically significant ($p = 0.093$), perhaps due to a limited number of cases. When comparing the cases with the comparison cohort, a significant difference was found in Preop, Postop, and Depth difference, but no difference was noted in the percent decrease (Table 2).

Discussion:

This study sought to understand the progression of the LFNS depth in pediatric patients who underwent ACL reconstruction following acute injury. Approximately 8 months following initial imaging, after undergoing ACLR without any additional surgical intervention to address the notch, the LFNS was found to decrease by 0.60 mm or 28%. These findings suggest that in pediatric patients with a positive LFNS, the depth does decrease following ACL reconstruction.

Wierer et al. performed a similar analysis on predominately adult patients who underwent ACL reconstruction.[18] Using MRI images from initial presentation and post-operative follow-up, they found that the depth of the LFNS did not decrease in this population, while the total area of the notch did significantly decrease. When patients who underwent primary ACLR present after a second knee injury, knowledge of changes in the LFNS can aid in radiographic assessment of ACL graft rupture. Our study found that at 8 months, the depth of the LFNS on radiograph had decreased significantly by 28% in those with a positive Preop LFNS. This suggests the resolution of the LFNS in pediatric patients who suffer ACL rupture may differ from adult patients. Future studies should aim to use advanced imaging techniques, such as MRI, to evaluate the area of the LFNS in order to compare resolution patterns between pediatric and adult patients.

The LFNS is an important identification on radiographs and may be significant in helping to determine if a patient initially presents with an ACL tear before obtaining an MRI. Furthermore, previous studies in adults have shown that the presence of a LFNS correlates with concomitant meniscus and anterolateral ligament (ALL) tears.[8,9] This study demonstrated a significant decrease in LFNS depth over time suggesting the potential resolution of the LFNS. However, MRI analysis is needed to understand if the LFNS sign similarly correlates with meniscal tears, ligamentous tears, or other markers of significant injury in the pediatric population following ACL rupture.

The incidence of a LFNS following ACL rupture has been cited anywhere from 7.5% to 52%.[8,9,20] However, these studies focused predominately on the adult population, with a mean age of participants between 23.3 to 29.4 years. The adult population primarily considers a positive LFNS if the depth is greater than 2.0 mm.[8] In this study, on patients with a median age of 16.3 years, 5.8% of patients had a LFNS that met our inclusion criteria of having a LFNS depth greater than 1.5 mm. The incidence found in this study suggests that pediatric LFNS may be less common that in the adult population. Alternatively, the notch created in pediatric patients may be shallower and, therefore, the threshold for a positive LFNS in pediatric knees may be smaller than in adults. Understanding the true incidence of pediatric LFNS can aid in the diagnosis of ACL rupture, thus, further studies should aim to assess the incidence of LFNS in pediatric patients compared to adults.

This study has several limitations. Many patients had to be excluded due to lack of post-operative radiographic assessments. Additionally, while our x-ray techniques were standardized, this study did not investigate if there was variability between different x-ray technicians. The small sample size limited the ability to further analyze LFNS depth by timepoint following surgical intervention. However, the authors believe that these limitations do not negate the findings of this study as statistically significant decreases in LFNS depth were found. Future studies should aim to group post-operative imaging by more discrete timepoints to further understand the resolution pattern of the LFNS.

Conclusion:

This study sought to understand the resolution of the LFNS following ACLR in pediatric patients. Following ACLR, the LFNS had decreased significantly by 28% at approximately 8 months. These findings suggest that unlike adults, the pediatric LFNS has the potential to resolve following ACLR.

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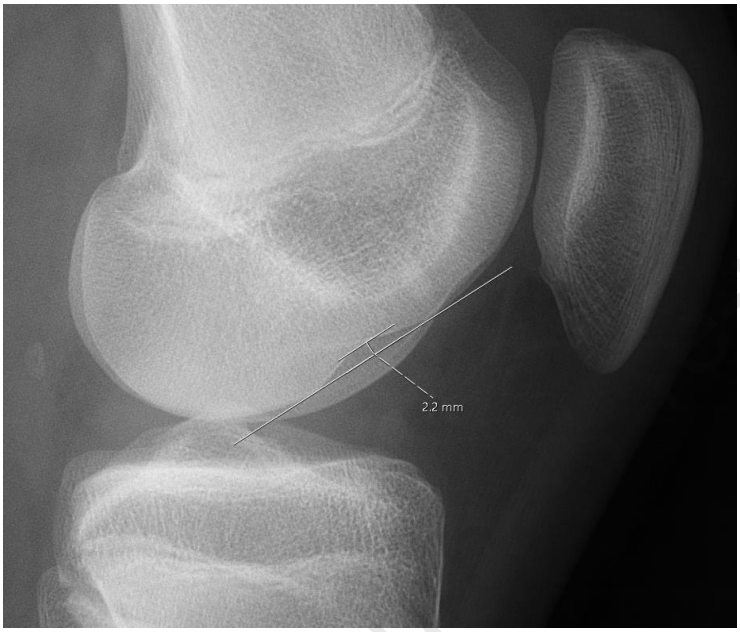

Figure 1: Example lateral knee radiograph demonstrated a 2.2 mm LFNS depth. A tangential line across the notch, intersecting the lower articular surface of the lateral condyle is used as a reference. A perpendicular line then measures the depth of the notch at the deepest point.

Table 1: Demographic information on patients with LFNS > 1.5 mm

Demographic	**Number**	**Percent**
Total Number	17	100%
Sex:		
Male	8	47.1%
Female	9	52.9%
Race		
White	11	64.7%

Black/African American	2	11.8%
Asian	2	11.8%
Native Hawaiin/Pacific Islander	1	5.9%
Unknown/Did Not Respond	1	5.9%
Ethnicity		
Hispanic	2	11.8%
Non-Hispanic	14	82.4%
Unknown/Did Not Respond	1	5.9%
Laterality		
Right	7	41.2%
Left	10	58.8%

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224 Table 2: Cases versus comparison cohort with Mann-Whitney U test p values. Values are represented as medians (IQR).
225 Statistically significant values are represented with a *.

Variable		Cases	Comparison Cohort	p value
Total		13	13	
Sex	**Male**	6	6	
	Female	7	7	
Laterality	**Right**	5	5	
	Left	8	8	
Age		16.3 (14.8 - 16.8)	15.7 (14.5 - 16.2)	0.186
Preop LFNS (mm)		1.70 (1.50 - 2.10)	0.69 (0.20 - 0.86)	<0.001*
Postop LFNS (mm)		1.50 (1.00 - 1.65)	0.48 (0.075 - 0.89)	<0.001*
Time between Radiographs		7.7 (1.9 - 19.2)	9.7 (1.5 - 19.6)	0.96
Depth Difference (mm)		0.60 (0.20 - 0.70)	0.00 (-0.02 - 0.20)	0.001*
Percent Decrease (%)		28.0 (11.4 - 42.0)	10.0 (-7.5 - 31.8)	0.106

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Laterality	**Right**	5	5	
	Left	8	8	
Age		16.26 (14.79 - 16.82)	15.70 (14.50 - 16.23)	0.186
Preop LFNS (mm)		1.70 (1.50 - 2.10)	0.69 (0.20 - 0.86)	<0.001*
Postop LFNS (mm)		1.50 (1.00 - 1.65)	0.48 (0.075 - 0.89)	<0.001*
Time between Radiographs		7.67 (1.88 - 19.17)	9.67 (1.47 - 19.60)	0.96
Depth Difference (mm)		0.60 (0.20 - 0.70)	0.00 (-0.02 - 0.20)	0.001*
Percent Decrease (%)		28.00 (11.44 - 42.02)	10.00 (-7.50 - 31.82)	0.106

Values are represented as medians (IQR). Statistically significant values are represented with a *.

LFNS = Lateral Femoral Notch Sign

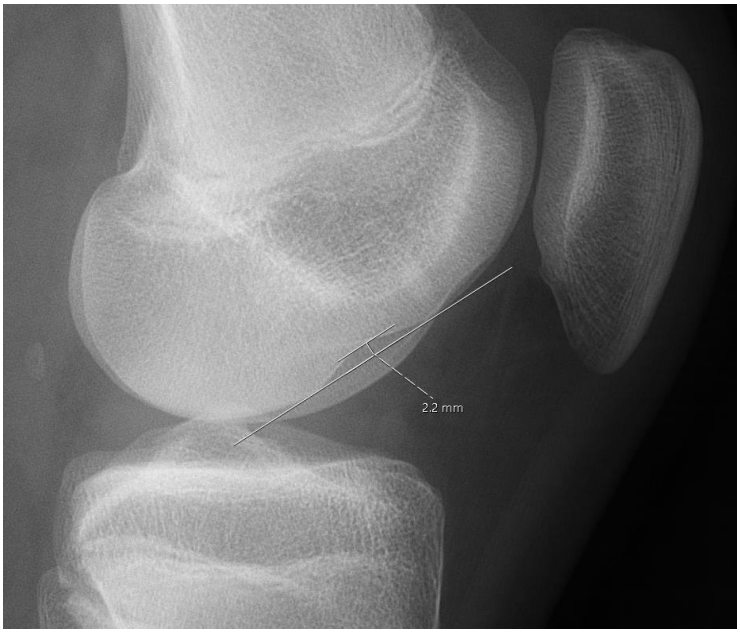

Figure 1: Example lateral knee radiograph demonstrated a 2.2 mm LFNS depth. A tangential line across the notch, intersecting the lower articular surface of the lateral condyle is used as a reference. A perpendicular line then measures the depth of the notch at the deepest point.

Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Daniel W. Green reports was provided by Hospital for Special Surgery. Daniel W. Green reports a relationship with American Academy of Orthopaedic Surgeons that includes: board membership. Daniel W. Green reports a relationship with AO Trauma Committee Italy that includes: speaking and lecture fees. Daniel W. Green reports a relationship with Arthrex Inc that includes: consulting or advisory and speaking and lecture fees. Daniel W. Green reports a relationship with Current Opinion in Pediatrics that includes: board membership and funding grants. Daniel W. Green reports a relationship with New York County Medical Society that includes: board membership. Daniel W. Green reports a relationship with NYS Society of Orthopaedic Surgeons that includes: board membership. Daniel W. Green reports a relationship with Patellofemoral Foundation that includes: board membership. Daniel W. Green reports a relationship with Pediatric Orthopaedic Society of North America that includes: board membership. Daniel W. Green reports a relationship with Pediatric Research in Sports Medicine that includes: board membership. Daniel W. Green reports a relationship with Wolters Kluwer Health that includes: funding grants. Douglas N. Mintz reports a relationship with American College of Radiology that includes: board membership. Douglas N. Mintz reports a relationship with Society of Skeletal Radiology that includes: board membership. Frank A. Cordasco reports a relationship with American Shoulder and Elbow Surgeons that includes: board membership. Frank A. Cordasco reports a relationship with Arthrex Inc that includes: consulting or advisory. Frank A. Cordasco reports a relationship with Saunders Mosby-Elsevier that includes: funding grants. Frank A. Cordasco reports a relationship with Wolters Kluwer Health that includes: funding grants. Peter D. Fabricant reports a relationship with Clinical Orthopaedics and Related Research that includes: board membership. Peter D. Fabricant reports a relationship with Osso VR that includes: equity or stocks. Peter D. Fabricant reports a relationship with Pediatric Orthopaedic Society of North America that includes: board membership. Peter D. Fabricant reports a relationship with Research in OsteoChondritis of the Knee (ROCK) that includes: board membership. Peter D. Fabricant reports a relationship with WishBone Orthopedics that includes: consulting or advisory. Daniel W. Green has patent with royalties paid to Arthrex, Inc. Daniel W. Green has patent with royalties paid to Current Opinion in Pediatrics. Daniel W. Green has patent with royalties paid to Pega Medical. Daniel W. Green has patent with royalties paid to Wolters Kluwer Health. Frank A. Cordasco has patent with royalties paid to Arthrex, Inc. Frank A. Cordasco has patent with royalties paid to Saunders/Mosby-Elsevier. Frank A. Cordasco has patent with royalties paid to Wolters Kluwer Health.