

Deep lateral notch sign and double notch sign in complete tears of the anterior cruciate ligament: MR imaging evaluation

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Received: 25 May 2014 / Revised: 2 November 2014 / Accepted: 5 November 2014 / Published online: 20 November 2014
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Abstract

Objective To systematically compare the notches of the lateral femoral condyle (LFC) in patients with and without complete tears of the anterior cruciate ligament (ACL) in MR studies by (1) evaluating the dimensions of the lateral condylopatellar sulcus; (2) evaluating the presence and appearance of an extra or a double notch and its association with such tears.

Materials and methods This retrospective study was approved by our institutional review board, and informed written patient consent was waived. In 58 cases of complete ACL tears and 37 control cases with intact ACL, the number of notches on the LFC was determined, and the depth and anteroposterior (AP) length of each notch were measured in each third of the LFC. The chi-square test, *t*-test, and logistic regression model were used to analyze demographic data and image findings, as appropriate.

Results Presence of more than one notch demonstrated a sensitivity of 17.2 %, specificity of 100 %, positive predictive value of 100 %, and negative predictive value of 43.5 % for detecting a complete ACL tear. Lateral third depth measure-

ment ($p=0.028$) was a significant associated finding with a complete ACL tear.

Conclusion A deep notch in the lateral third of the LFC is a significant associated finding with a complete ACL tear when compared with an ACL-intact control group, and the presence of more than one notch is a specific but insensitive sign of such a tear.

Keywords Magnetic resonance imaging · Anterior cruciate ligament of the knee

Introduction

The condylopatellar sulcus of the lateral femoral condyle (LFC) is a shallow groove separating the patellar and tibial articular surfaces of the femur [1]. It is located lateral to the most anterior aspect of the intercondylar notch and has a triangular shape with its base lying laterally [2]. It is well seen on conventional lateral radiographs, normally dividing the articular surface of the LFC in half [3]. It is also commonly known as the terminal sulcus.

The presence of a deep lateral sulcus (or notch) has been described on conventional radiographs as an indirect sign of a tear of the anterior cruciate ligament (ACL), representing an osteochondral fracture of the LFC [2, 4] (Fig. 1). The proposed mechanism for this finding is the impaction of the posterior aspect of the lateral tibial plateau on or around the area of the lateral condylopatellar sulcus. A sulcus deeper than either 1.5 or 2.0 mm has been shown as a specific but insensitive radiographic sign of an ACL-deficient knee [2, 4].

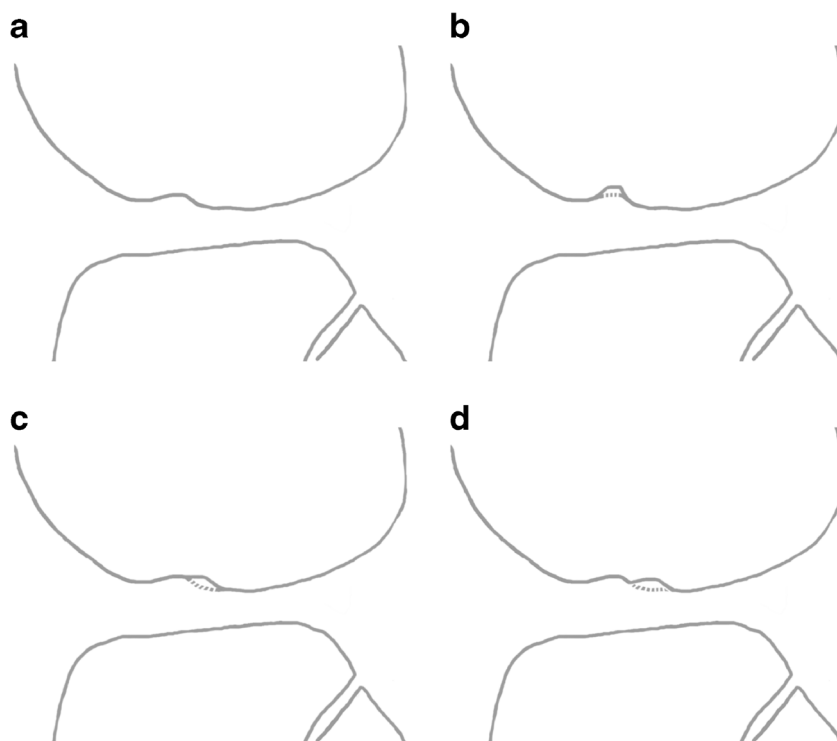
Although MR imaging has been shown to allow detection of osteochondral fractures in the region of the lateral condylopatellar sulcus, including the finding of bone marrow edema, associated with acute trauma [5], to the best of our

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Fig. 1 Drawing of a sagittal slice of the lateral portion of the knee, representing the hypothetical types of notches that can be found in ACL-torn cases, owing to slightly different impaction patterns: (a) normal notch, the condylopatellar sulcus; (b) a deep notch, owing to an impaction at the site of the condylopatellar sulcus; (c) a long notch; (d) a double notch, both owing to an impaction posterior to the condylopatellar sulcus. Dotted lines indicate the original bone contour



knowledge, there has been no study that emphasizes the dimensions of the normal or abnormal lateral sulcus, in a fashion similar to what has been done with conventional radiographs. Compared to conventional radiographs, MRI does not magnify structures and, being a multiplanar imaging method, it reduces superimposition and allows observation of the lateral notches in more than one slice, potentially altering the measurements of its dimensions and also potentially altering the previously described association between the deep notches and ACL tears.

Also present in the literature is the designation “abnormal lateral notches” in cases of ACL tears, used to describe bone irregularities or depressions that are seen at a different site or those that extend further posteriorly when compared to the contralateral uninjured knee [6]. No numeric criteria regarding the length of “long notches” exist, however. Anecdotal reports of an extra notch posterior to the lateral condylopatellar sulcus in cases of ACL tears can also be found [7] (Fig. 1).

Even though MR imaging is highly sensitive and specific in the detection of an ACL tear [8, 9], additional indirect signs of such a tear may be particularly useful in the few cases in which direct ligament visualization is not conclusive. Objective criteria for the detection of associated osteochondral fractures may also help in determining their potential role in the pathophysiology of subsequent osteoarthritis [10, 11].

Therefore, the purpose of this study was to systematically compare the notches of the lateral femoral condyle (LFC) in patients with and without complete tears of the anterior cruciate ligament (ACL) in MR studies by (1) evaluating the

dimensions of the lateral condylopatellar sulcus and (2) evaluating the presence and appearance of an extra or a double notch and its association with such tears.

Materials and methods

Study population

This retrospective study was approved by our institutional review board, and informed written patient consent was waived. A review of 64 arthroscopically proven cases of complete ACL tears from one fellowship-trained orthopedic surgeon consecutively selected from 2001 to 2005 was undertaken at our own institution. The electronic medical records of all patients were reviewed. Inclusion criterion consisted of confirmation of a complete tear on arthroscopic examination. Exclusion criteria included: (1) prior ACL reconstruction and/or (2) prior history of rheumatologic or musculoskeletal disorders affecting the knee. Injuries were categorized according to the time interval between the injury and the acquisition of the MR images: acute was defined as 0–6 weeks; subacute as 6 weeks to 6 months; chronic as greater than 6 months [12]. Additionally, 37 patients with intact ACL by MR imaging criteria were consecutively selected over a 4-month period from imaging studies done in 2009 or 2010 as the control group. Reasons for imaging were pain in 34 cases, suspected meniscal tear in 7 cases, and a palpable mass in 3 cases (in some cases, more than 1 reason was given). The footprints of

the ACL were thoroughly interrogated to prevent the inclusion of cases of chronic scarred ACL-torn cases in this group.

Image acquisition and analysis

All MR imaging examinations were performed with a 1.5-T superconducting magnet (Signa, General Electric Medical Systems) and a quadrature transmit-receive, four-coil phased array extremity coil (Medrad, Indianola, PA). All knees were placed in the neutral position and immobilized with foam pads. Imaging was performed in the coronal, sagittal, and transverse planes. Although several different magnets were employed with minor variations in imaging protocol, a standard MR imaging protocol was used in most cases, which included: axial proton density with fat suppression (TR/TE range 2,500–3,500/12–18), coronal proton density with fat suppression (2,500–3,000/15–19), coronal T1-weighted (400–800/12–20), sagittal T2-weighted (2,500–4,200/62–122), sagittal proton density (2,200–4,000/15–19), and sagittal STIR (3,400–5,500/20–30) sequences. Other imaging parameters included the following: number of excitations, 1; matrix range, 256 × 256 to 512 × 512; field of view range, 12–16 cm; slice thickness range, 2.5–4 mm.

MR images were reviewed by a musculoskeletal radiologist (A.G.) with 4 years of experience and a musculoskeletal radiology research fellow (H.S.) with 1 year of experience. Utilizing sagittal non-fat-suppressed proton density (PD) images, the number of notches on the LFC was determined in consensus. Then, cross-referencing with transverse images, the LFC was divided into lateral, central, and medial thirds, in consensus, and the depth of the notch(es) and its anteroposterior (AP) length were measured independently (Fig. 2). Those measurements were an adaptation of the previous methodology described for conventional radiographs

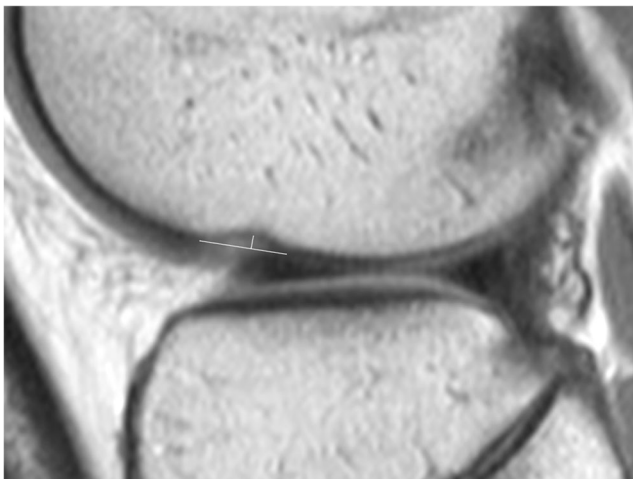


Fig. 2 Sagittal PD-weighted MR image of the knee of a 30-year-old male with a complete tear of the ACL shows the measurement technique for AP length (long white line) and depth (short white line) of a notch in the lateral third of the LFC

[2]. When a notch was not present, its depth and AP length were recorded as 0. The presence of bone marrow edema around the area of the notches was also recorded by one reader (A.G.). The Osirix v.5.8 Picture Archiving and Communication System was used to review the images.

Statistical analysis

IBM SPSS v21.0 was used for statistical analysis. Descriptive statistics were performed on the study groups and box plots were performed. Demographics between the two groups were compared using an independent samples *t*-test (age) and chi-square test (gender). Sensitivity, specificity, and positive and negative predictive values were calculated based on the finding of more than one notch. Thereafter, only the measurement of the condylopatellar sulcus was included in the remainder of the analysis for those patients with more than one notch. A two-way mixed intraclass correlation coefficient (ICC) was applied to assess interobserver agreement for each measurement. The ICC ranged from 0 to 1.00, with 0.00 to 0.39 for poor, 0.40 to 0.59 for fair, 0.60 to 0.74 for good, and 0.75 to 1.00 for excellent reliability [13].

Using the average value from both readers, independent samples *t*-test was used to compare the two groups based on notch dimensions (depth and AP length) in the lateral, central, and medial third regions. Box plots were generated for the significantly different means. Logistic regression analysis was performed using backward model selection to determine the best associated findings with a complete ACL tear.

Results

Demographics and age of injury

Of the 64 cases of arthroscopically proven ACL tears, 6 studies were eliminated because of evidence of prior ACL surgery, resulting in 58 cases (mean age 28.9 years, SD 9.3 years; 18 females, 40 males); in the control group there were 37 cases (mean age 34.0, SD 9.9 years; 20 females, 17 males). There was no statistically significant difference in age between the two groups ($p=0.13$). However, the case group had a significantly higher proportion of males ($p=0.03$). Regarding age of injury, 19 cases were acute injuries, 8 were subacute, and 10 were chronic. That information was not available in 21 cases.

Presence of multiple notches

No cases in the control group had more than one notch, whereas 10 out of 58 cases (17.2 %) in the ACL tear group had more than one notch (Fig. 3). Presence of more than one

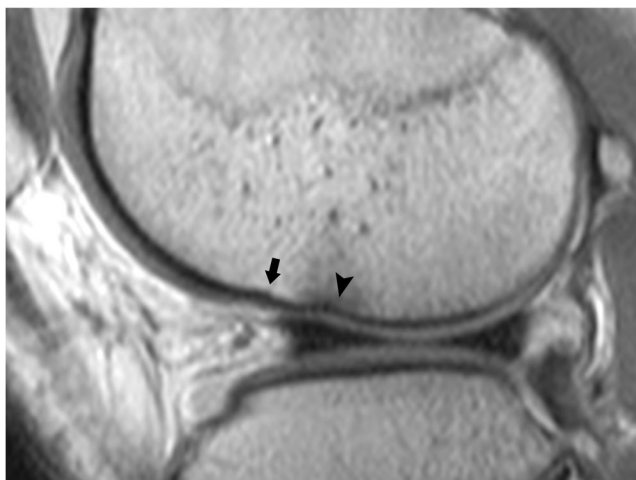


Fig. 3 Sagittal PD-weighted MR image of the knee of a 25-year-old male with a complete tear of the ACL shows the presence of a double notch (arrow: anterior notch; arrowhead: posterior notch) in the lateral third of the LFC. Bone marrow edema is present beneath the posterior notch

notch demonstrated a sensitivity of 17.2 %, specificity of 100 %, positive predictive value of 100 %, and negative predictive value of 43.5 % for detecting a complete ACL tear.

Notches dimensions

The ICC for both readers is summarized in Table 1. Medial AP length measurement had good reliability. All other measurements had excellent reliability. AP length and depth of notches in both ACL-intact and ACL-torn groups are summarized in Table 2 and Fig. 4. Depth of notches in the lateral, central, and medial thirds was significantly greater for the ACL-torn group ($p < 0.05$). Differences in AP length were not significant for the lateral and central thirds, but were significant between the two groups for the medial third ($p < 0.05$). There were no significant differences between males and females for notch depth of the lateral, central, and mid thirds in the control group ($p = 0.886, 0.460, \text{ and } 0.451$, respectively), ACL tear group ($p = 0.476, 0.166, \text{ and } 0.178$, respectively), and all patients ($p = 0.259, 0.236, \text{ and } 0.133$, respectively).

Using backward model selection, the final logistic regression analysis model showed that the lateral third depth

Table 1 Intraclass correlation coefficient (ICC) for both readers

| Measurement | ICC* |
|---------------------------|---------------------|
| Lateral third – AP length | 0.892 (0.837–0.929) |
| Lateral third – depth | 0.956 (0.934–0.971) |
| Central third – AP length | 0.875 (0.797–0.920) |
| Central third – depth | 0.952 (0.920–0.970) |
| Medial third – AP length | 0.727 (0.591–0.818) |
| Medial third – depth | 0.798 (0.693–0.867) |

*Numbers in parentheses are 95 % confidence intervals

measurement ($p = 0.028$) and medial third AP length ($p = 0.005$) were significant associated findings with a complete ACL tear. Lateral third depth measurement of 0.7 mm corresponded to a sensitivity of 66 % and specificity of 70 %. Using a measurement of 0.9 mm, specificity increased to 89 %, but sensitivity decreased to 49 %. Medial third AP length of 0.5 cm corresponded to a sensitivity of 60 % and specificity of 81 %.

Presence of bone marrow edema

Bone marrow edema was present beneath the notches in 100 % (19/19) of acute injuries, 37.5 % (3/8) of subacute injuries, 40 % (4/10) of chronic injuries, and 28.5 % (6/21) of cases in which age of injury was unknown.

Discussion

In this study, we have demonstrated that the depth of the lateral condylopatellar sulcus measured on an MR image at the level of the lateral third of the LFC is a significant associated finding with a complete ACL tear, when compared with an ACL-intact control group. We also demonstrated that the presence of more than one notch on the LFC is a very specific indirect sign of a complete ACL tear, although insensitive, when compared with an ACL-intact control group. To the best of our knowledge, this is the first time this association has been demonstrated.

We also demonstrated that the AP length of a sulcus on the medial third of the LFC is a significant associated finding with a complete ACL tear when compared with an ACL-intact control group. However, the evaluation of the articular surface in this third was limited by its oblique orientation, resulting in the occurrence of partial volume-averaging artifacts. As a consequence, there was some disagreement between the observers on the measurements taken, as expressed by the lower, but still acceptable ICC. Additionally, in only a small fraction of the cases, there was a measurable notch in this third, and there was also some disagreement on its assessment (the presence or absence of a notch). Therefore, we believe that results derived from this third of the LFC should be interpreted with caution.

Independent samples t-tests also showed that notch depth in the central and medial thirds was significantly different between ACL-torn and ACL-intact groups; however, logistic regression analysis did not demonstrate this to be a significant associated finding with an ACL tear.

MR imaging is highly sensitive and specific in the detection of an ACL tear [8, 9], but its performance is reported to be slightly worse in chronic cases [14]. One of the factors contributing to this is the scarring patterns of a torn ACL that

Table 2 Dimensions of notches in each third of the LFC in ACL-torn patients and ACL-intact controls (average between both readers)

| | No tear group* | ACL tear group* | <i>P</i> value** |
|---------------------------|-----------------------------|-----------------------------|------------------|
| Lateral third – AP length | 0.94 cm ± 0.59 [0.74, 1.13] | 1.13 cm ± 0.47 [1.00, 1.25] | 0.088 |
| Lateral third – depth | 0.52 mm ± 0.44 [0.37, 0.67] | 0.82 mm ± 0.44 [0.71, 0.93] | 0.001 |
| Central third – AP length | 1.00 cm ± 0.40 [0.86, 1.13] | 1.11 cm ± 0.45 [0.99, 1.23] | 0.203 |
| Central third – depth | 0.58 mm ± 0.34 [0.47, 0.69] | 0.77 mm ± 0.43 [0.66, 0.88] | 0.026 |
| Medial third – AP length | 0.21 cm ± 0.41 [0.08, 0.35] | 0.6 cm ± 0.53 [0.46, 0.73] | < 0.001 |
| Medial third – depth | 0.16 mm ± 0.34 [0.04, 0.27] | 0.51 mm ± 0.45 [0.38, 0.63] | < 0.001 |

*Data are mean measurements ± standard deviation. Number in brackets is 95 % confidence interval

***P* value was calculated with independent samples t-tests. *P* < 0.05 denotes a significant difference

sometimes simulate an intact ligament with MR imaging [15]. In these cases, utilizing the deep lateral notch as an indirect sign of a ligament tear might prove particularly useful. Also,

in many chronic cases, the bone marrow edema that is observed during the acute phase of injury might have resolved [11], and contour abnormalities in the subchondral bone plate

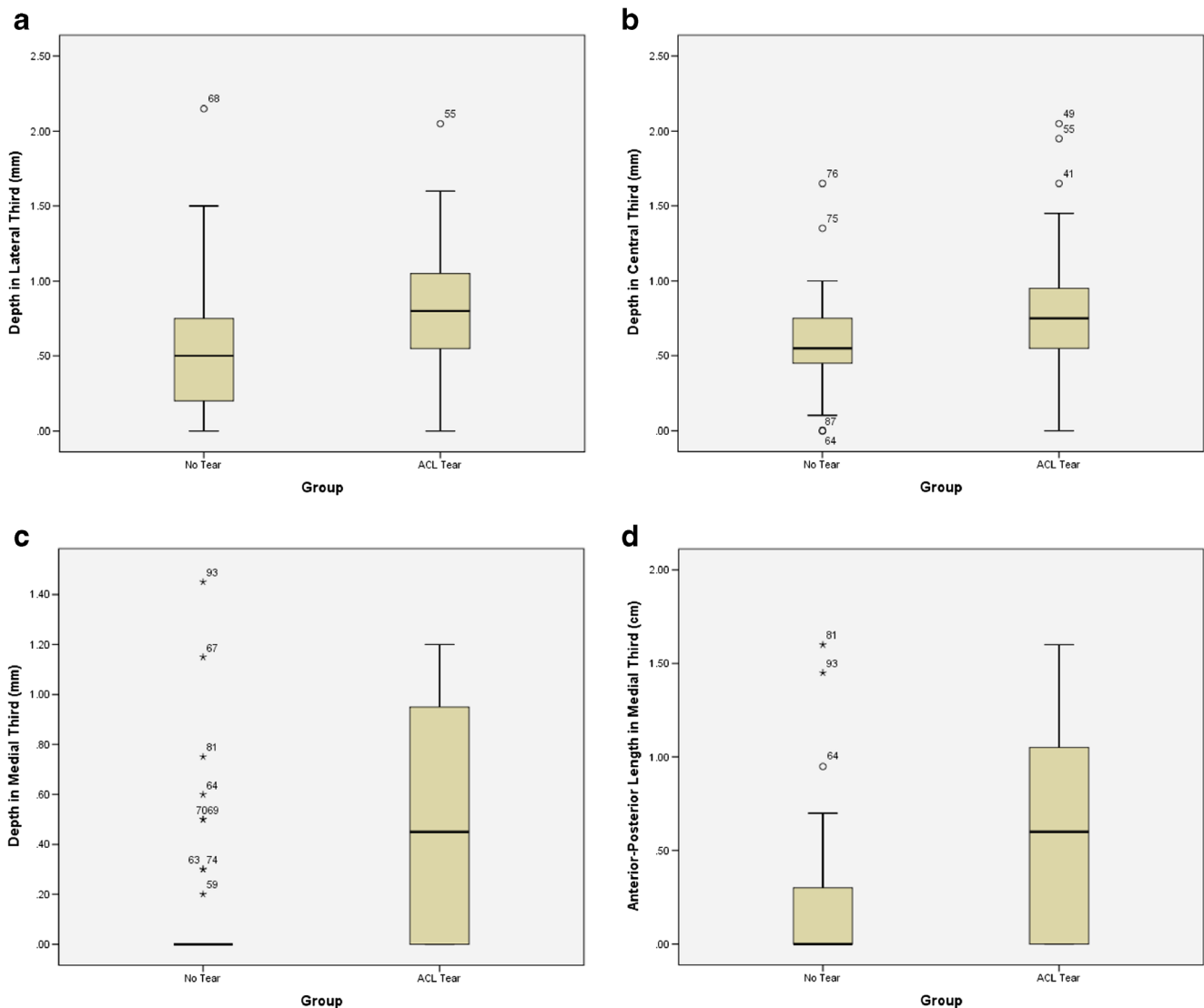


Fig. 4 Box plots generated for the measurements of notch depth in the (a) lateral, (b) central, and (c) medial third of the LFC and (d) AP length in the medial third

might be the only sign that an osteochondral fracture had occurred.

The clinical relevancy of detecting these osteochondral fractures is still debated. There is an association of prior ACL tears and the early onset of osteoarthritis [16, 17], but this association does not seem to be completely explained simply by joint instability caused by ACL insufficiency, because even in ACL-reconstructed knees, early degenerative changes have been observed [18]. Some believe that biomechanical changes in the joint due to alterations in the articular surface caused by these fractures may play a role in the pathophysiology of subsequent osteoarthritis [10, 11].

Surgical treatment for these osteochondral fractures has been proposed, including reduction of the fracture and chondroplasty [10, 19, 20], but this is usually reserved for the more severe cases. Specific criteria for deciding which patients should undergo this type of treatment are yet to be determined. Data gathered in the present study might be useful in designing future prognostic or therapeutic studies addressing these issues.

There were several limitations to this study, the first of them being its retrospective nature. Second, the observers were not blinded to the presence or absence of an ACL tear when reviewing images, which may have resulted in observation bias. It would have been very difficult to blind the observers regarding the status of the ACL, however, as portions of the ligament were clearly visible when the condylar bone surface was being analyzed. Additionally, no age or gender correction was performed when selecting control patients. No sample size calculation was performed prior to patient selection. No surgical confirmation was obtained regarding ACL integrity in the control patients; rather, only MR imaging criteria was used, although it has been shown that these criteria are highly accurate [8, 9]. Care was taken not to include chronic scarred ACL-torn cases in the control group, but it is possible that cases with a chronic ligament tear that had scarred perfectly to the native footprint might have been inadvertently included. The determination of which notch was the true lateral condylopatellar sulcus in double notch cases was done subjectively and, because there are no established criteria to make this determination, there may have been misjudgment in some cases. We did not use any correction factor to account for differences in LFC dimensions among patients, and it is conceivable that the normal lateral condylopatellar sulcus dimensions may vary in differently sized condyles. Finally, the patients included in this study had either a complete tear of the ACL or an intact ACL. Caution should be made when generalizing our results to other groups, such as patients with partial tears of the ACL.

In conclusion, using MR imaging for assessment, a deep notch in the lateral third of the LFC is a significant associated finding with a complete ACL tear, when compared with an

ACL-intact control group, and the presence of more than one notch is a specific but insensitive sign of such a tear.

Acknowledgments Eric Y. Chang, MD, gratefully acknowledges grant support from the VA Clinical Science Research and Development Career Development Award (IK2CX000749)

Conflict of interest The authors declare that they have no conflict of interest.

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