Association of the Coronal Lateral Collateral Ligament Sign in ACL-Deficient Knees With Greater Anterior Tibial Translation and Femorotibial Rotation in Adults and Adolescents

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Background: The coronal lateral collateral ligament (LCL) sign (the entire LCL being seen in 1 coronal slice on a magnetic resonance imaging [MRI] scan), is a new secondary sign of anterior cruciate ligament (ACL) tear.

Purpose: To (1) evaluate the coronal LCL sign in adults with ACL tears and (2) compare the magnitude of the MRI scan parameters between adolescent and adult ACL-deficient knees with positive coronal LCL signs.

Study Design: Cross-sectional study; Level of evidence: 3.

Methods: We retrospectively reviewed patients who underwent ACL reconstruction between February 1, 2013, and May 31, 2021, and divided them into adolescent (10-18 years) and adult (>18 years) groups. Tibial translation, femorotibial rotation, and presence of the coronal LCL sign were evaluated using MRI. The static femorotibial position parameters were also compared between positive and negative coronal LCL sign groups. Independent Student *t* tests were used to identify statistically significant differences for continuous variables, whereas the categorical variables were compared using the chi-square test.

Results: A total of 65 adolescents and 300 adults with ACL tears were identified. The coronal LCL sign was present in a similar percentage of adolescents and adults with ACL tears (57% vs 58%; $P = .873$). The anterior tibial translation (ATT) in patients with positive coronal LCL signs (adolescents, 7.9 ± 3.4 mm; adults, 6.6 ± 3.5 mm) was significantly greater compared with those with negative signs (adolescents, 1.5 ± 2.6 mm, $P < .001$; adults, 2.3 ± 4.2 mm, $P < .001$). Femorotibial rotation was also statistically greater in positive coronal LCL sign groups (adolescents, 6.4° ± 5.6°; adults, 7.0° ± 5.0°) compared with negative sign groups (adolescents, 0.7° ± 4.7°, $P < .001$; adults, 3.5° ± 4.2°, $P < .001$).

Conclusion: The occurrence of the coronal LCL sign on MRI scans was comparable between adolescents and adults with ACL-deficient knees. The presence of the LCL sign was associated with a greater ATT and femorotibial rotation in both adolescents and adults with ACL tears.

Keywords: anterior cruciate ligament; anterior tibial translation; coronal lateral collateral ligament sign; femorotibial rotation; magnetic resonance imaging

Anterior cruciate ligament (ACL) injury is a common orthopaedic injury,[16] especially in young athletes who participate in sports that require pivoting and jumping.[2] As a stabilizer that prevents anterior translation and internal rotation of the tibia relative to the femur (femorotibial rotation), the ACL is often injured during landing with a fully extended knee in valgus and an internally rotated tibia.[8,13]

Magnetic resonance imaging (MRI) is the most accurate diagnostic imaging modality for ACL tears.[15] In addition to primary signs of ACL injury, secondary signs, such as bone

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bruising, posterior cruciate ligament angulation, and posterior displacement of the posterior horn of the lateral meniscus, are important when the MRI scan appearance of the ACL is equivocal.[6,10]

The novel coronal lateral collateral ligament (LCL) sign on MRI scans has been proposed as a secondary sign for identifying ACL injury, especially in adolescent patients.[11,14] The coronal LCL sign is considered to be positive when the entire LCL is observed in a single coronal MRI scan section. Mitchell et al[11] reported that a positive coronal LCL sign is associated with ACL-deficient knees, greater anterior tibial translation (ATT), and femorotibial rotation. They also determined that a positive coronal LCL sign on an MRI scan indicates a greater risk of graft failure after ACL reconstruction.[12]

Previous studies that have evaluated the coronal LCL sign in ACL deficient knees only enrolled adolescent patients.[11,12] In the current study, we aimed to (1) evaluate the coronal LCL sign in adults with ACL tears and (2) compare the magnitude of the MR image parameters between adolescent and adult ACL-deficient knees with positive coronal LCL signs. We hypothesized that the incidence of the coronal LCL sign and the degree of ATT and femorotibial rotation on MRI in patients with positive coronal LCL signs would be similar between adults and adolescents.

METHODS

After the study protocol received institutional review board approval, we retrospectively identified patients who underwent ACL reconstruction at a single medical center between February 1, 2013, and May 31, 2021. The inclusion criteria were patients with ACL injuries warranting reconstruction and preoperative MRI scan of the injured knee. The exclusion criteria included incomplete imaging, poor-quality images, concomitant multiligament knee injury requiring surgical treatment, and the presence of implants. The demographic data collected were age, sex, and laterality. Patients were divided into 2 groups: the adolescent group, which represented patients between the ages of 10 and 18 years, as defined by the World Health Organization, and the adult group, which represented patients aged >18 years.

Using a radiology information system (INFINITT PACS; INFINITT Healthcare Co Ltd), all radiographic measurements were performed by 2 authors (Y.-J.L. and T.-A.C.). MRI was performed using a 1.5-T MRI scanner (GE Discovery MR450; GE HealthCare). Following the standardized MRI protocol for knee examinations at our institution, the patients were in the supine position with the knee in 10° to 15° of flexion and neutral rotation. A small proportion (8%) of the cohort underwent imaging at an outside institution. These images were used in this study only if in-house imaging data were not available.

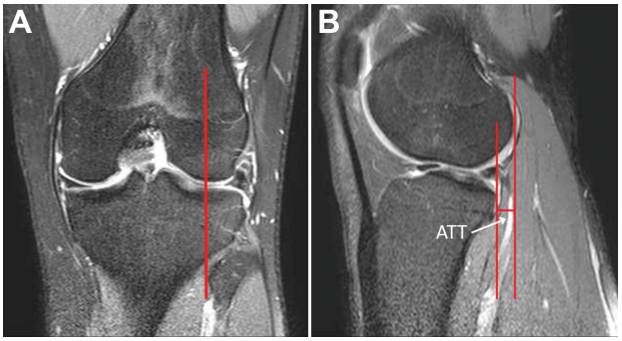

Figure 1. ATT was measured using proton density-weighted MRI sequences. (A) The midsagittal plane of the lateral femoral condyle (red line) was identified on coronal images. (B) Two vertical lines were drawn from the posterior aspects of the subchondral bone of the lateral femoral condyle and lateral tibial condyle. The shortest distance between the 2 vertical lines was considered the ATT. ATT, anterior tibial translation; MRI, magnetic resonance imaging.

Tibial translation was measured using the method described by Kalegowda et al[5] (Figure 1). Using the coronal images, we identified the midsagittal plane of the lateral femoral condyle on the proton density-weighted sequences. ATT was defined as the distance between 2 parallel lines drawn at the posterior aspects of the lateral femoral condyle and lateral tibial condyle.[5] Tibial translation was assigned a positive value in the case of anterior translation and a negative value in the case of posterior translation.

Femorotibial rotation was measured using the method described by Vassalou et al,[19] shown in Figure 2. Using axial MRI, femoral rotation was defined as the angle between the horizontal line and a line tangent to the posterior cortex of femoral condyles. Tibial rotation was measured 1 slice above the proximal end of the fibula and defined as the angle between the horizontal line and a line tangent to the most prominent point of the posterior

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Ethical approval for this study was obtained from National Cheng Kung University Hospital (reference no. A-ER-110-437).

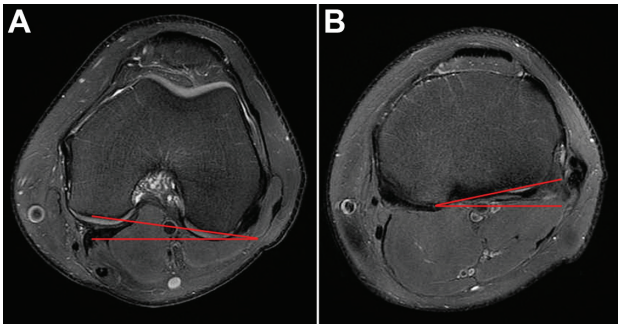

Figure 2. Femorotibial rotation was measured on axial MRI scans. (A) Femoral rotation is the angle between horizontal line and tangential line to the posterior cortex of the femoral condyles. (B) Tibial rotation is the angle between the horizontal line at and tangential line to the most prominent point of the posterior cortex of the tibial condyles. Femorotibial rotation was calculated as the absolute difference between the femoral and tibial rotations, which was given a positive value for internal rotation and a negative value for external rotation.[19] MRI, magnetic resonance imaging.

Figure 3. Coronal T2-weighted fat-suppressed MRI showing a positive lateral collateral ligament sign (red arrow). MRI, magnetic resonance imaging.

cortex of the tibial condyles. Femorotibial rotation was calculated as the absolute difference between the femoral and tibial rotations, which was given a positive value for internal rotation and a negative value for external rotation.[19]

The coronal LCL sign was considered positive when the entire LCL, extending from the femoral origin to the fibular insertion, was seen in 1 coronal slice on MRI (Figure 3).[11]

TABLE 1
Demographic Data of Study Cohort[a]

Parameter	Adolescents (n = 65)	Adults (n = 300)	*P*
Age, y	16.8 ± 1.2	29.9 ± 9.6	
Sex			<.001
Male	32 (49%)	231 (77%)	
Female	33 (51%)	69 (23%)	
Laterality			.079
Right	23 (35%)	142 (47.3%)	
Left	42 (65%)	158 (52.7%)	
LCL sign			.873
Positive	37 (57%)	174 (58%)	
Negative	28 (43%)	126 (42%)	

[a]Data are reported as mean ± SD or n (%). LCL, lateral collateral ligament.

Statistical Analysis

Data analysis was performed using SPSS (Version 22; IBM Corp), and the α level was set at .05 for statistical significance. The presence of coronal LCL sign was compared between adolescent and adult groups, whereas the static tibiofemoral position parameters were compared between positive and negative coronal LCL sign groups. Post hoc power analysis was performed with G*Power Version 3.1.3 (Heinrich Heine-University of Dusseldorf) to calculate the achieved power. Data normality was evaluated using the Shapiro-Wilk test, and homogeneity of variance was assessed using the Levene test. $P > .05$ was considered indicative of data normality and variance homogeneity.

Continuous variables were reported as means and standard deviations, and independent Student *t* tests were used to identify statistically significant differences between the 2 groups. A nonparametric Mann-Whitney *U* test was used when the assumptions of the parametric tests were violated. Categorical variables were compared using the chi-square test. For reliability between observers of the coronal LCL sign, the intraclass correlation coefficient (ICC) was used, and ICC values of >0.60 and >0.74 were considered good and excellent reliability, respectively.[7]

RESULTS

Patient Demographics

Preoperative MRI scans of ACL-deficient knees of 65 adolescents and 300 adults were reviewed. Demographic data are summarized in Table 1. The mean age of the adolescent cohort was 16.8 ± 1.2 years, and that of the adult cohort was 29.9 ± 9.6 years. Laterality was not significantly different between the 2 cohorts.

Coronal LCL Sign and Static Tibiofemoral Position

The percentage of coronal LCL positivity in ACL-injured knees was similar between adolescents and adults

TABLE 2
ATT and Femorotibial Rotation[a]

	ATT, mm		Femorotibial Rotation, deg	
Parameter	Adolescents	Adults	Adolescents	Adults
LCL sign				
Positive	7.9 ± 3.4	6.6 ± 3.5	6.4 ± 5.6	7.0 ± 5.0
Negative	1.5 ± 2.6	2.3 ± 4.2	0.7 ± 4.7	3.5 ± 4.2
P	<.001	<.001	<.001	<.001

[a]Data are reported as mean ± SD. ATT, anterior tibial translation; LCL, lateral collateral ligament.

(P = .873) (Table 1). The ICC for identifying the coronal LCL sign was 0.92, indicating excellent interobserver reliability.

Radiographic measurements of the ATT and femorotibial rotation are reported in Table 2. The mean ATT was 5.1 ± 4.4 mm in adolescents and 4.8 ± 4.4 mm in adults, with no difference between groups (P = .585). No difference in the mean femorotibial rotation was found between the adolescent and adult groups (3.9° ± 5.9° vs 5.5° ± 4.9°; P = .44). In adolescents, ACL-injured knees with a positive LCL sign had significantly greater tibial translation (7.9 ± 3.4 vs 1.5 ± 2.6 mm; $P < .001$) and femorotibial rotation (6.4° ± 5.6° vs 0.7° ± 4.7°; $P < .001$) than those with a negative LCL sign. Similarly, the presence of the LCL sign in adults was associated with significantly greater tibial translation (6.6 ± 3.5 vs 2.3 ± 4.2 mm; $P < .001$) and femorotibial rotation (7.0° ± 5.0° vs 3.5° ± 4.2°; $P < .001$) (Table 2).

The calculated effect size was 0.96 for comparing the means of femorotibial rotation between patients with and without LCL signs in adults. Given the α level of .05, the post hoc achieved power was 96%.

DISCUSSION

The major findings of the present study were that the coronal LCL sign was present in a similar percentage of adolescents (57%) and adults (58%) with ACL tears and that the presence of the coronal LCL sign was associated with significantly greater ATT and femorotibial rotation in both adolescents and adults ($P < .001$ for all).

The novel coronal LCL sign on an MRI scan has been proposed as a secondary sign of ACL injury.[11,14] Although the coronal LCL sign is reportedly associated with a greater ATT and femorotibial rotation in adolescent ACL-deficient knees, it remains unclear whether the same can be seen in adult patients. In this study, we were able to establish that the coronal LCL sign can be observed in more than half of adult patients with ACL tears. Furthermore, the presence of the coronal LCL sign in adults with ACL-deficient knees was associated with a greater ATT and femorotibial rotation on MRI scan.

Identifying the coronal LCL sign may be clinically important. A previous study revealed that the coronal LCL sign persists over time, indicating a greater risk of graft failure after ACL reconstruction.[12] However, only adolescent patients were enrolled in that study.[12] Our study determined that the occurrence of the coronal LCL sign in ACL-deficient knees in adults was similar to that in adolescents. Future studies are required to confirm whether this sign is also associated with graft failure after ACL reconstruction in adults.

Although the results from different studies cannot be compared directly, the findings in the present study are generally consistent with those of previous studies. Previous studies have reported a 5.6 to 6.0 mm ATT in adults with ACL tears[5,18] and a mean of 5.8 mm in adolescent ACL-deficient knees.[11] Similarly, the present study reported a mean ATT of 5.1 mm and 4.8 mm in adolescents and adults with ACL-deficient knees, respectively. Vassalou et al[19] suggested a femorotibial rotation of 4.9° to indicate a complete ACL tear, whereas Mitchell et al[11] described a mean angle of 5.2° in adolescents with ACL tears. Similarly, the present study determined a mean angle of 3.9° and 5.5° in adolescents and adults with ACL-deficient knees, respectively.

The coronal LCL sign is a static knee laxity sign. Similar to a previous study,[11] the present study showed that ACL-deficient knees with coronal LCL signs had greater ATT and femorotibial rotation than those without LCL signs, in both adolescents and adults. Currently, whether static knee laxity represents dynamic knee instability remains controversial. Some studies have indicated that anterior tibial subluxation is associated with high-grade rotatory laxity in ACL-deficient knees.[1,9] Other studies have reported that the occurrence of the coronal LCL sign is not associated with dynamic anterior tibial laxity or rotatory knee laxity.[3,4] Despite these inconclusive findings, knee laxity should be evaluated routinely regardless of static knee laxity signs.

Limitations

Our study had some limitations. First, a healthy control group was lacking and the incidence of the coronal LCL sign could not be determined. The incidences of the coronal LCL sign in ACL-deficient knees and healthy controls have been reported in adolescents, being 68.6% and 18.6%, respectively.[11] Another study that included healthy participants aged from 15 to 78 years reported a 4.3% incident rate of the coronal LCL sign.[14] With a lack of studies that focus on adult population only, the incidence of the coronal LCL sign in healthy adults remains unclear. Second, the imaging measurements could potentially be affected by the MRI protocol. Limited by the retrospective design of the current study, a small proportion of patients underwent MRI at an outside hospital. Hence, the uniformity of the protocol could not be ensured. Third, the sex proportions of adolescents and adults were different in the present study. Therefore, the results for adolescents and adults should be interpreted with caution. Fourth, the MRI was performed only in a static and supine position in this study. Upright, open MRI should be considered in the future to analyze potential dynamic knee instability.[17]

CONCLUSION

The occurrence of the coronal LCL sign on MRI was comparable between adolescents and adults with ACL-deficient knees. The presence of the LCL sign was associated with a greater ATT and femorotibial rotation in both adolescents and adults with ACL tears.

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