Association of Increased Lateral Femoral Condylar Ratio With Lateral Meniscus Posterior Root Tear in Noncontact ACL Injury

Nam-Hong Choi,* MD, Bong-Seok Yang,† MD, Dong-Min Lee,‡§ MD, and Choong-Ryul Lee,‡ MD
Investigation performed at Eulji Medical Center, Seoul, Republic of Korea

Background: In the setting of anterior cruciate ligament (ACL) injury, lateral meniscus posterior root tears (LMPRTs) are less readily diagnosed on preoperative magnetic resonance imaging (MRI). Therefore, to predict LMPRTs in ACL injuries, it is necessary to understand the risk factors associated with them.

Purpose/Hypothesis: The purpose of this study was to investigate the association of lateral femoral condylar ratio (LFCR) with LMPRTs in ACL injuries. It was hypothesized that an increased LFCR would be associated with LMPRTs in noncontact ACL injuries.

Study Design: Cohort study; Level of evidence, 3.

Methods: Enrolled were consecutive patients who underwent primary acute (<6 weeks from injury) ACL reconstruction after noncontact injury and had LMPRT confirmed on preoperative MRI and arthroscopically (combined group; n = 62) as well as patients who underwent isolated acute ACL reconstruction (isolated group; n = 80) who were matched to the combined group by age, height, and body mass index (BMI). All patients underwent surgery between January 1999 and November 2021. LFCR and posterior tibial slope (PTS) were measured and compared between the isolated and combined groups. The area under the receiver operating characteristic curve (AUC) was calculated to determine the cutoff for detecting increased risk of LMPRTs.

Results: The demographic characteristics of the 2 groups did not differ significantly, nor did the PTS. The LFCR was a significant factor (odds ratio [OR], 1.23; P = .001) associated with LMPRT. Patient age, height, BMI, and PTS were not associated with LMPRT. The AUC (0.66; 95% CI, 0.57-0.75) for LFCR had a sensitivity of 39% and specificity of 90% to predict LMPRT. The calculated cutoff associated with an increased risk for LMPRT when compared with the isolated group was 67.0% (OR, 4.98; 95% CI, 2.10-11.79).

Conclusion: Increased LFCR was associated with the presence of LMPRTs in patients with acute ACL injuries. The LFCR may provide surgeons with additional information regarding the risk of having a concomitant LMPRT when planning ACL reconstructions.

Keywords: anterior cruciate ligament; noncontact injury; lateral meniscus posterior root tear; lateral femoral condylar ratio

Meniscal injuries are commonly associated with an anterior cruciate ligament (ACL) tear, and their incidence ranges between 47% and 65%.[13,16,17,20] A multicenter cohort study reported that 31% of 600 patients with ACL tear had lateral meniscal tears, of which the most common was a root tear.[13] A lateral meniscus posterior root tear (LMPRT) is biomechanically harmful. Although a complete radial tear can occur at the midbody, posterior horn, or posterior root of the lateral meniscus, a detrimental effect on the load distribution and transmission functions is greatest in the posterior root tear.[18] LMPRTs at the time of ACL injuries increase anterior tibial subluxation of the lateral compartment compared with isolated ACL tear.[24]

Preoperative diagnosis of LMPRTs using magnetic resonance imaging (MRI) is necessary for surgical planning and decisions about postoperative rehabilitation. However, the sensitivity and specificity in diagnosis of LMPRTs in

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preoperative MRI are variable.[1,20] A recent study reported that 67% of LMPRTs were missed on preoperative MRI.[14] Therefore, careful MRI interpretation and a high index of suspicion of LMPRTs are necessary. Understanding risk factors associated with LMPRTs may be helpful in treating patients with ACL injuries. Several risk factors, including increased posterior tibial slope (PTS), associated medial meniscal ramp lesion, and contact sports injury, have been investigated.[2,11] Increased lateral condylar depth is among several altered bony morphologies of the knee associated with increased risk of an ACL tear and medial meniscal ramp lesion.[9,10,19] The lateral femoral condylar ratio (LFCR) is the ratio of the length of the posterior condyle to the length of the entire lateral condyle. Increased LFCR potentially causes the lateral and anterolateral structures to tighten more in flexion than in extension.[15]

As the association of LFCR with LMPRT has not been reported in literature, the purpose of this retrospective study was to investigate the association of LFCR with LMPRTs in ACL injuries. It was hypothesized that an increased LFCR would be associated with LMPRTs in noncontact ACL injuries.

METHODS

Study Population

Consecutive patients who underwent primary acute (<6 weeks from injury) ACL reconstruction after noncontact injury and had LMPRT confirmed on preoperative MRI and arthroscopically (combined group) were enrolled in this study. An LMPRT was defined as a radial or oblique tear ≤10 mm of the posterior root attachment during arthroscopy.[4] All patients underwent surgery between January 1999 and November 2021. During the same period, patients who underwent isolated acute ACL reconstruction (isolated group) were matched by age, height, and body mass index (BMI) with the combined group. Patients in both groups had the same inclusion and exclusion criteria. Patients with acute ACL tear by another injury mechanism, chronic ACL tear, and concomitant ligament reconstruction were excluded. A previous study reported that increased LFCR is a risk factor for ramp lesion or red-red zone tear of the medial meniscus.[10] These meniscal tears were excluded. Patients were also excluded if their lateral radiographs of the affected knee showed an overlap of >6 mm between the posterior margins of the medial and lateral condyles.[11] Patients whose MRI had poor quality when measuring the PTS were excluded. The study protocol was approved by an institutional review board, and all study patients provided written informed consent.

Plain Radiographs and MRI Measurements

Lateral radiographs and preoperative MRI were available for all included patients. True or nearly true lateral radiographs of the knee were confirmed in all patients. True lateral view showed perfect superimposition of the posterior aspect of the medial and lateral condyles of the distal femur. Nearly true lateral view showed <6 mm of overlap between the posterior halves of the medial and lateral condyles.[19]

A method described by Pfeiffer et al[19] was used to measure the LFCR. Two circles separated by 5 cm were centered on the distal femoral shaft. A line connecting the center of both circles was considered the longitudinal axis of the distal femoral shaft. Another line perpendicular to the axis of the distal femoral shaft was drawn from between the most anterior point and the most posterior point of the lateral condyle (lateral condylar length). The distance from the intersection of the above 2 lines to the most posterior point of the condyle was divided by the lateral condylar length and multiplied by 100%. This ratio was defined as the LFCR (Figure 1).

All MRI examinations were performed on either a 1.5-T (Siemens Avanto) or 3.0-T (Siemens Skyra) system. The PTS on the lateral tibial plateau was measured as described previously.[8] On a central sagittal image showing the tibial attachment of the posterior cruciate ligament, 2 circles were drawn: a proximal circle whose boundary was the anterior, posterior, and proximal tibial cortical bone and a distal circle whose boundary was the anterior and posterior cortex border. The center of the distal circle was located on the circumference of the proximal circle. A line connecting the centers of the 2 circles was regarded as the longitudinal axis of the proximal tibia (line a in Figure 2A). On a sagittal view at the middle of the lateral tibial plateau, a line perpendicular to the longitudinal axis of the proximal tibia was drawn, and another line tangential to the lateral tibial plateau was drawn. The angle between the 2 lines was defined as the PTS (asterisk in Figure 2B).

All PTS measurements were performed by an orthopaedic fellow who was blinded to the patient group. The measurements were repeated 3 weeks later, and the intraobserver reliability was calculated using the intraclass correlation coefficient (ICC).

§Address correspondence to Dong-Min Lee, MD, Department of Orthopedic Surgery, Gwangmyeong Sungae Hospital, 36 Digital-ro, Gwangmyeong, 04917, Republic of Korea (email: drdmlee@gmail.com).

*Department of Orthopedic Surgery, Eulji Medical Center, Seoul, Republic of Korea.

†Department of Orthopaedic Surgery, Shihwa Medical Center, Siheung, Republic of Korea.

‡Department of Orthopedic Surgery, Gwangmyeong Sungae Hospital, Gwangmyeong, Republic of Korea.

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Ethical approval for this study was obtained from Nowon Eulji Medical Center, Eulji University (reference No. EMCS 2021-12-024).

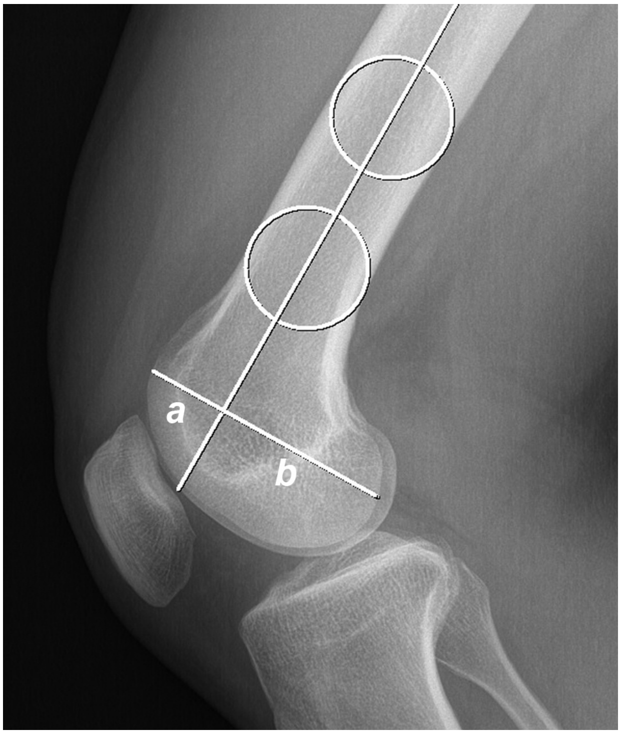

Figure 1. On a lateral radiograph, a longitudinal line on the distal femur connecting the centers of 2 circles separated by 5 cm was drawn. A line perpendicular to the longitudinal line of the distal femur was drawn from between the most anterior point and the most posterior point of the lateral femoral condyle. The distance from the intersection of these 2 lines to the most posterior point of the condyle (*b*) was divided by the distance between the most anterior point (line *a*) and the most posterior point of the lateral condyle (*a* + *b*). The lateral femoral condylar ratio was calculated as *b*/(*a* + *b*) × 100%.

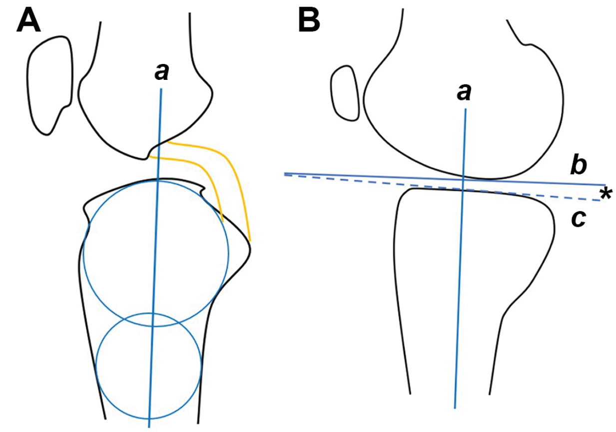

Figure 2. (A) Diagram showing the longitudinal axis of the proximal tibia (line *a*) as the line connecting the centers of the 2 circles on a sagittal image; the yellow lines indicate the tibial attachment of the posterior cruciate ligament. (B) Diagram showing a line perpendicular (line *b*) to the longitudinal axis of the proximal tibia (line *a*). Another line tangential to the lateral tibial plateau was drawn (line *c*), and the angle between lines *b* and *c* (*) was defined as the posterior tibial slope.

Statistical Analysis

LFCR and PTS are reported as mean and standard deviation. Measurements of LFCR and PTS were compared between isolated and combined groups using the independent *t* test. Sample size was calculated using previously published literature.[8,10] For a power of 0.8 and an alpha value of .05, calculated sample sizes of LFCR and PTS were 25 and 24 in each group, respectively. Therefore, the numbers of patients in the 2 groups had sufficient power for statistical analysis without type II error. The primary outcome was LFCR and the secondary outcome was PTS. The receiver operating characteristic curve and area under the receiver operating characteristic curve (AUC) with its 95% CI were calculated. The AUC was tested by a 2-sided binomial Z test with a significance level of 0.05. The optimal cutoff value was determined at the maximal Youden index. The odds ratio (OR) was calculated. Multiple regression analysis was performed to investigate whether LFCR, PTS, age, and BMI were risk factors for LMPRT. Data were analyzed using SPSS statistical package (Version 25.0; SPSS) and G*Power program (Version 3.1.5; http://www.gpower.hhu.de/). Significance level was set at .05.

RESULTS

A total of 1333 patients underwent ACL reconstruction surgery during the study period. After exclusion of 1191 patients, 142 patients were eligible for this study (80 patients in the isolated group and 62 patients in the combined group) (Figure 3). A comparison of the demographic characteristics of the 2 groups is described in Table 1. Age, height, and BMI of the 2 groups did not differ significantly. The LMPRTs were repaired with all-inside suture repair in 28 patients and a fixation device (FasT-Fix; Smith & Nephew) in 18 patients. Partial meniscectomy was done in 9 patients with tears involving the red-white zone, and 7 patients showed partial healing at the time of arthroscopy. The ICCs for the intraobserver reliability for the LFCR and the PTS were 0.88 (95% CI, 0.82-0.93) and 0.90 (95% CI, 0.85-0.94), respectively, indicating good reliability.

The LFCR was 64.0% ± 2.5% (range, 58.1%-72.8%) in the isolated group and 65.9% ± 3.6% (range, 59.4%-73.6%) in the combined group ($P < .001$). The PTS did not differ between the 2 groups ($P = .057$) (Table 2). The LFCR was a significant factor (OR, 1.23; $P = .001$) associated with LMPRT. Age, height, BMI, and PTS were not associated with LMPRT. The AUC (0.66; 95% CI, 0.57-0.75) for LFCR had a sensitivity of 39% and specificity of 90% to predict LMPRT (Figure 4). The calculated cutoff for LFCR that was associated with an increased risk for LMPRT was 67.0% (OR, 4.98; 95% CI, 2.10-11.79) when compared with the isolated group.

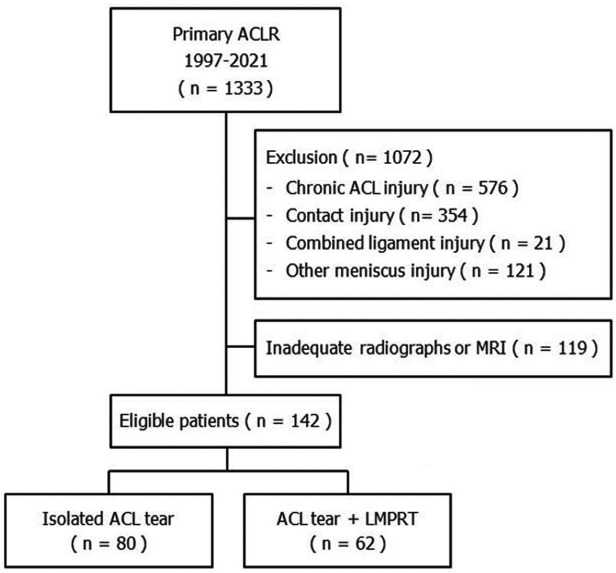

Figure 3. Flowchart showing patient enrollment in the study. ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; MRI, magnetic resonance imaging; LMPRT, lateral meniscus posterior root tear.

TABLE 1
Preoperative Characteristics of the Isolated and Combined Groups[a]

Characteristic	Isolated (n = 80)	Combined (n = 62)	P
Age, y	28.2 ± 10.4 (15-54)	26.4 ± 11.1 (16-48)	.330
Height, cm	173.7 ± 7.3 (153-189)	173.9 ± 7.4 (161-188)	.862
BMI, kg/m^2	24.4 ± 3.5 (19.4-34.8)	24.4 ± 3.4 (18.2-33.9)	.969

[a]Data are reported as mean ± SD (range). BMI, body mass index.

TABLE 2
LFCR and PTS of the Isolated and Combined Groups[a]

	Isolated (n = 80)	Combined (n = 62)	*P*
LFCR, %	64.0 ± 2.5	65.9 ± 3.6	**<.001**
PTS, deg	6.7 ± 3.4	5.5 ± 3.6	.057

[a]Data are reported as mean ± SD. Boldface *P* value indicates statistically significant difference between groups ($P < .05$). LFCR, lateral femoral condylar ratio; PTS, posterior tibial slope.

DISCUSSION

The most important finding of this study was that an increased LFCR was associated with LMPRT. The calculated cutoff associated with an increased risk for LMPRT was 67.0% (OR, 4.98) when compared with the isolated group. However, an increased PTS was not associated with an increased risk for LMPRT.

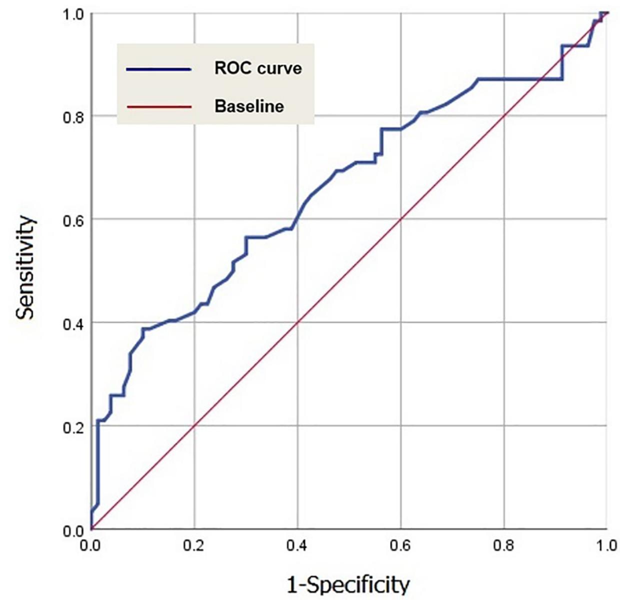

Figure 4. The ROC curve of LFCR for predicting significantly increased risk of LMPRTs. The area under the ROC curve (0.66; 95% CI, 0.57-0.75) for LFCR had a sensitivity of 39% and specificity of 90% to predict LMPRT. ROC, receiver operating characteristic; LFCR, lateral femoral condylar ratio; LMPRT, lateral meniscus posterior root tear.

LMPRTs usually occur after acute trauma in relatively young patients and are commonly associated with ACL tears.[6] Koo et al[12] reported 19 of 20 patients with LMPRTs had ACL tears. Although biomechanical properties have been investigated extensively for the root tear of the medial meniscus, there is a paucity of literature concerning biomechanical evaluation of LMPRTs. Walczak et al[22] investigated functional behavior of the lateral meniscus during axial compression load and dynamic knee motion. Posterior root detachment of the lateral meniscus resulted in a maximum extrusion of 1.65 ± 0.97 mm in full extension. Koo et al reported mean extrusion was 0.9 mm (range, –1.9 to 3.4 mm) in patients with LMPRT. Although extrusion of the midbody after LMPRT is minimal, LMPRTs decrease contact area significantly and increase mean and peak contact pressures in the lateral compartment.[23] LMPRTs in ACL injuries have shown increased internal rotation and anterior tibial translation compared with isolated ACL injuries.[4] Therefore, evaluation of LFCR, a risk factor of LMPRT, is necessary for accurate diagnosis of LMPRT before surgery.

Altered bony morphologies of the knee are known as risk factors for noncontact ACL injuries. Narrow intercondylar notch and increased PTS have been extensively investigated.[5,7,21] A steeper tibial posterior slope may increase the axial compression load, which could cause the lateral femoral condyle to slide posteriorly off from the lateral tibial plateau, increasing the strain on an ACL and the inherent risk of rupture.[3] An increased PTS is also associated with LMPRT.[2,11] Bernholt et al[2] compared the PTS between an ACL tear with LMPRT group and isolated ACL tear group. Patients with LMPRTs had a significantly steeper PTS (9.1° vs 7.0°; P = .001). Kim et al[11] reported that the risk of LMPRT in ACL-injured knees increased with PTS (OR, 1.293; 95% CI, 1.061-1.576; P = .011). However, this current study did not demonstrate that an increased PTS is associated with increased risk of LMPRT. The isolated group tended to show steeper PTS than the combined group. The PTS values vary greatly between studies. The study-to-study differences in so-called normal tibial slope exceed the difference between controls and ACL-injured patients. Therefore, the PTS in this study may be different from that in other studies.

Increased lateral condylar depth was recently investigated as a risk factor for noncontact ACL injuries.[9,10,19] Increased lateral condylar depth can exaggerate the pivoting mechanism that is the rolling of the lateral femur from its round flexion radius to its more flattened part near extension on the convex lateral tibial plateau.[6] Pfeiffer et al[19] reported that the mean and standard deviation of LFCR was 61.2% ± 2.4% in the control group, 64.2% ± 3.8% in the primary ACL injury group, and 64.4% ± 3.6% in the failed ACL reconstruction group, respectively. Patients who had a primary ACL injury or failed ACL reconstruction had significantly higher LFCR compared with the control group ($P < .008$). The LFCR of >63% was significantly associated with a higher risk of ACL injury (OR, 8.0; 95% CI, 4.1-15.7) when compared with the control group. A recent study[10] demonstrated that an increased LFCR was associated with the risk of ramp lesion in knees with ACL injuries (OR, 62.9; $P < .001$) and the cutoff value of LFCR was 0.71. An increased lateral femoral condylar depth potentially results in increased length of the lateral and anterolateral structures of the knee in flexion, causing the lateral and anterolateral structures to tighten more in flexion than in extension.[15] Resulting anisometry may be associated with an increased risk for LMPRT. However, an association of increased posterior condylar depth with LMPRT has not been described in literature.

This current study demonstrated that increased lateral femoral condylar depth is a risk factor for LMPRT. However, increased LFCR does not mean presence of LMPRT at time of ACL reconstruction or alter treatment for LMPRT. Therefore, careful evaluation of preoperative MRI is needed to find LMPRTs in ACL-injured patients with an increased LFCR. Decision of treatment method for LMPRT depends on reparability. Although increased LFCR may affect healing of repaired LMPRT or may be a risk factor for retear, the effect of increased LFCR on clinical outcomes needs to be investigated in future studies.

Limitations

There are several limitations in this study. First, many ACL-injured patients with chronic injury or unacceptable radiographs or MRI were excluded from this study. Patient exclusions can affect the results of a study. Second, patients with acute ACL tears due to a noncontact mechanism were enrolled in this study. Because injury mechanism was dependent on recall memory of the patients, incorrect memory of the patients could affect the number of patients in the isolated and combined groups. Third, all patients and control participants were Asian. Ethnic differences in the morphology and dimension of the distal femur may exist.

CONCLUSION

Increased LFCR was associated with the presence of LMPRTs in patients with acute ACL injuries. The LFCR may provide surgeons with additional information regarding the risk of having a concomitant LMPRT when planning for ACL reconstruction surgery.

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