# ANTERIOR CRUCIATE LIGAMENT INJURY : MR IMAGING WITH SURGICAL CORRELATION

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## ABSTRACT

**OBJECTIVE.** To determine the sensitivity, specificity, and accuracy of primary and secondary signs of ACL tear in MR imaging. **MATERIAL AND METHODS.** MR images of the knee in 31 patients who had surgical correlation were retrospectively reviewed by two radiologists who did not know the surgical results or the original interpretation. Surgery (open surgery or arthroscopy) demonstrated complete ACL tear in 9 patients and intact ACL in 22 patients. The appearance of ACL in sagittal T1/T2WI, coronal T1/T2WI, the anterior translation of tibia, the uncovered lateral meniscus sign, and the curvature of PCL were evaluated. **RESULTS.** The primary sign of ACL tear (abnormal morphology & signal intensity) had respective sensitivity, specificity, and accuracy of 100%, 86.3%, 90.3% on sagittal T1WI; 100%, 90.9%, 93.5% on sagittal T2WI; 75%, 95.2%, 89.7% on coronal T1WI; and 77.7%, 90.4%, 86.7% on coronal T2WI. The secondary signs of ACL tear had respective sensitivity, specificity, and accuracy of 77.7%, 100%, 93.1% for anterior translation of tibia at 5-mm cut off; 44.4%, 100%, 82.8% for uncovered lateral meniscus sign; and 87.5%, 90%, 89% for the buckling of PCL. CONCLUSION. Among the primary sign of ACL tear, an abnormal appearance of ACL on sagittal T2WI is most accurate. Anterior translation of tibia and uncovered lateral meniscus sign are secondary signs that have the highest specificity in diagnosing ACL tear.

## INTRODUCTION

Magnetic resonance (MR) imaging is the most accurate and noninvasive technique for determining the status of anterior cruciate ligament (ACL).[1-6] The integrity of the ACL is, however, occasionally difficult to assess, particularly when the ACL is not entirely included on a single sagittal image.[7-10] In this situation, secondary sign of ACL tear may be useful to support the presumptive diagnosis of ACL tear. These signs refer to indirect findings on the MR imaging examination that suggest the presence of ACL tear because of either an inferred mechanism of injury or an instability pattern with ACL deficiency. We investigated the sensitivity, specificity, and accuracy of (a) abnormal morphologic features and signal intensity (SI) of ACL assessed on sagittal and coronal images and (b) secondary signs of ACL tear including anterior translation of tibia, uncovered lateral meniscus sign, and the curvature of posterior cruciate ligament (PCL).

## MATERIAL & METHODS

Preoperative MR images were evaluated

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of 31 knees of patients whose ACL status had been surgically confirmed (by arthroscopy or open surgery) and in whom MR imaging had been performed in at least two planes. Twenty-two knees with intact ACL and 9 knees with complete ACL tear were proved surgically. MR images were retrospectively reviewed by two radiologists without knowledge of physical examination or surgical findings.

MR imaging examinations of the knee were performed with a 1.5-T magnet (Signa; GE Medical System, Milwaukee, WI). The knee was positioned in the extremity coil with the patient in supine position and the leg straightened. The machine was angled parallel to medial border of lateral femoral condyle. In sagittal plane, T1-, proton-density, and T2-weigthed images (T2WI) were obtained with spin echo (SE) using repetition time / echo time (TR [msec] / TE [msec]) 400/17, 4000/20-100, 3 signal average, 256x192 matrix, 20x15 - 22x16 cm field of view, and 3-mm slice thickness with 1-mm gap. In coronal plane, there were T1-weighted SE sequence using TR/TE 600-680/20 msec., and gradient recalled echo (GRE) sequence with TR/TE 600-680/20 msec., flip angle 25 degrees, 3 signal average.

**Primary sign of ACL tear.** The ACL was diagnosed as "normal" when it appeared as a band of fibers of low signal intensity on T1-, proton-density, and T2-WI. The normal orientation or slope of the ACL parallels to the femoral intercondylar roof. Abnormalities of both signal intensity (SI) and morphologic features referred to as primary MR imaging signs of ACL tear. The ACL was diagnosed as "torn" when focal or diffuse increased SI within the ligament was noted on T1-, proton-density, and T2-WI. Morphologic criteria used to support diagnosis of tear included an irregular, wavy contour of the ligament, a decreased slope of residual ACL, or an absence of ACL (Fig. 1).

**Secondary sign of ACL tear.** In this study, we used three secondary signs to support the diagnosis of ACL tear 1) anterior translation of tibia,[7] 2) uncovered lateral meniscus sign,[11] and 3) buckling of posterior cruciate ligament (PCL).[7] Anterior translation of tibia. The measurement was obtained at midsagittal plane of the lateral femoral condyle.[7] Two vertical lines were drawn tangent to posterior cortex or lateral femoral condyle and posterior cortex of lateral tibial plateau, and the distance was electronically measured and recorded as millimeters (Fig. 2). Uncovered lateral meniscus sign. Posterior displacement of the lateral meniscus compared with the posterior margin of lateral tibial plateau has been described as an indirect sign of complete ACL tear.[11,12] This sign was positive if a vertical line drawn tangently to the posteriormost cortical margin of lateral tibial plateau on sagittal image intersects any part of posterior horn of lateral meniscus. This sign was negative if this vertical line did not intersect the lateral meniscus (Fig. 3). Buckling of posterior cruciate ligament (PCL). The PCL was considered buckled if it demonstrated a sharp angulation apex posteriorly,[7] and was recorded as present or absent (Fig. 4).

**Statistical Analysis.** We performed Fisher Exact test to evaluate sensitivity, specificity, and accuracy of the primary sign and secondary sign of ACL tear, and performed Mann-Whitney U test to study the median value of anterior translation of tibia.

## RESULT

Table 1 reveals the sensitivity, specificity, and accuracy of primary signs of ACL tear. Table 2 shows the results of secondary signs. Mann-Whitney U test revealed the median value of anterior translation of tibia to be 0.75 mm when the ACL was intact and 7.8 mm when the ACL was torn ($p < 0.0001$).

**TABLE 1** Sensitivity, specificity, and accuracy of primary sign of ACL tear

| Sequence | Sensitivity | Specificity | Accuracy | P-value |
|---|---|---|---|---|
| Sagittal T1 | 100 | 86.3 | 90.3 | < 0.0001 |
| Sagittal T2 | 100 | 90.9 | 93.5 | < 0.00001 |
| Coronal T1 | 75 | 95.2 | 89.7 | < 0.001 |
| Coronal T2 | 77.7 | 90.4 | 86.7 | < 0.001 |

**TABLE 2** Sensitivity, specificity, and accuracy of secondary sign of ACL tear

| Sign | Sensitivity | Specificity | Accuracy | P-value |
|---|---|---|---|---|
| Anterior translation of tibia | 77.7 | 100.0 | 93.1 | —— |
| Uncovered lateral meniscus | 44.4 | 100.0 | 82.7 | < 0.01 |
| Buckling of PCL | 87.5 | 90.0 | 89.0 | < 0.01 |

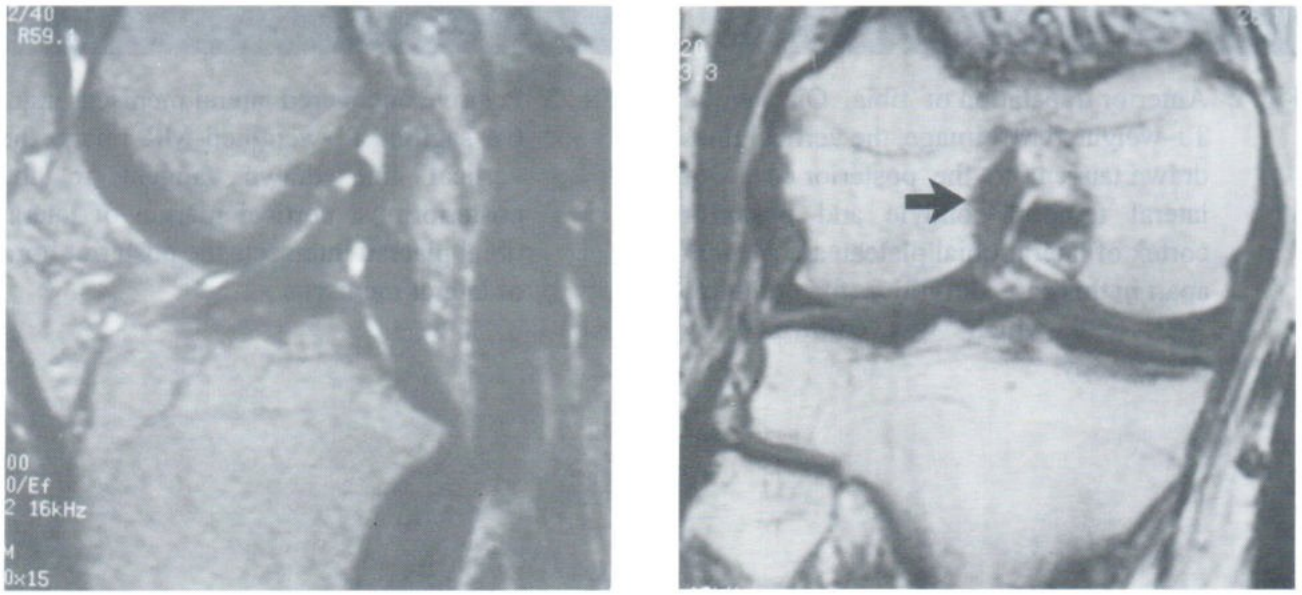

**Fig. 1** Complete ACL tear. a) Sagittal T2-weighted MR image reveals focally increased SI in the mid portion of ACL. Decreased slope of the ACL is also observed. This is a 26-year-old male athlete presented with history of knee injury for 4 months. b) T1-weighted coronal MR image shows increased SI of the ACL in the intercondylar notch (black arrow). Decreased swelling of the ligament is due to timing of injury.

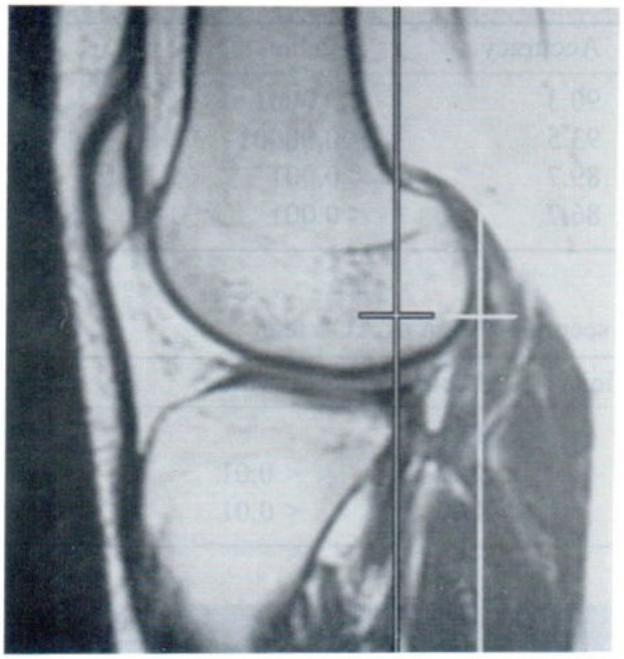

**Fig. 2** Anterior translation of tibia. On sagittal T1-weighted MR image, the vertical lines drawn tangent to the posterior cortex of lateral femoral condyle and posterior cortex of lateral tibial plateau are 21 mm apart in this case, definitive for complete ACL tear which was confirmed by arthroscopy.

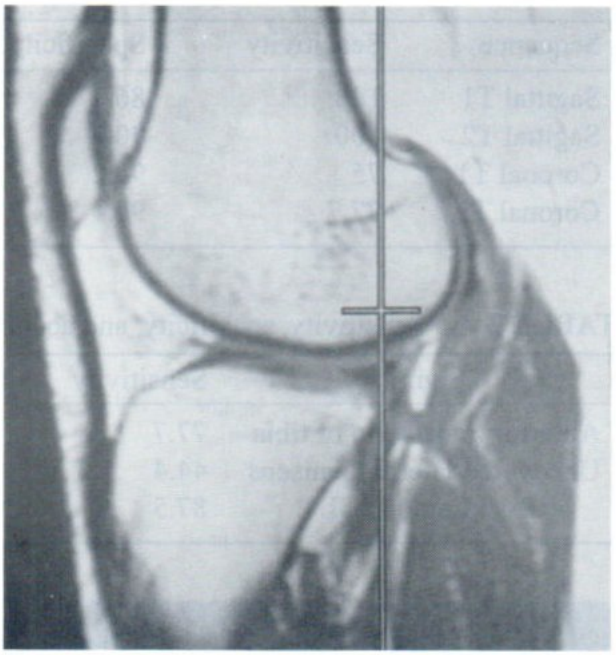

**Fig. 3** Positive uncovered lateral meniscus sign. On sagittal T1-weighted MR image, the vertical line drawn tangent to the posteriormost cortical margin of lateral tibial plateau intersects the posterior horn of lateral meniscus.

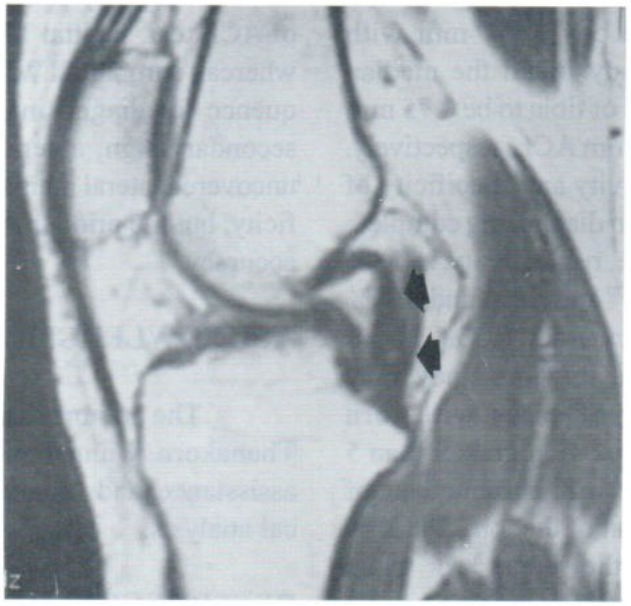

**Fig. 4** Present buckling of PCL. Sagittal T1-weighted MR image reveals posterior angulation of the PCL. The PCL is outlined by the black arrows.

## DISCUSSION

MR imaging has been reported to be accurate in showing the normal and injured anatomy of the ACL.[8,13-19] The distinction of complete tears from partial tears is clinically important because the presence of a partial tear is not an indication for surgical reconstruction.[20-23] Conversely, patients with complete ACL tear may have functional disability that can lead to meniscal injury and osteoarthritic changes.[20] Previous reports have emphasized the advantages of T2WI sagittal images in improving sensitivity, with overall accuracy rate of 95%.[3,24] In our study, the accuracy of T2W sagittal images for diagnosing complete ACL tear is 93.5%, corresponding to previous studies. We also found that sagittal T2W sequence was the most accurate sequence among those used in evaluating primary sign of ACL tear, whereas coronal T1WI showed the highest specificity (95%). However, diagnosing ACL tear can be difficult in certain situations. The whole length of an intact ACL may not be seen on one sagittal image in 5-10% of patients,[4,25] resulting misinterpretation as tear. Contrary, ACL may appear to be abnormal on sagittal MR image in the absence of ligamentous tear due to the presence of mucoid or eosinophilic degeneration within the ligament.[6,26] In addition, suboptimal selection of the sagittal imaging plane, volume averaging of the ligament with effusion in the intercondylar notch (or with the lateral femoral condyle or the periligamentous fat), as well as pulsation artifacts originating in the popliteal artery[7] may also cause diagnostic problems.[6-8] In these circumstances, other MR signs of ACL tear may have a role.

Secondary sign of ACL tear in MR imaging were investigated by many authors.[1,4,6,7,20,27,28] When the ACL is deficient, the tibia may become displaced anteriorly.[28] Vahey et al.[7] reported anterior translation of tibia at the level of midsagittal lateral femoral condyle to be 0.8 $\pm$

0.6 mm when the ACL was intact, 4.1 ± 1.0 mm with acute ACL tear, and 5.8 ± 0.7 mm with chronic ACL tear. Our study found the median value of anterior translation of tibia to be 0.75 mm and 7.8 mm with intact and torn ACL, respectively. Using 5 mm cut off, sensitivity and specificity of anterior translation of tibia in diagnosing complete ACL tear was reported to be, respectively, as 58% and 93%,[7] 86% and 99%,[20] and 78% and 100% by our study. The higher accuracy (93%) in our results compared with 69% in previous study[7] may be due to small number of cases with torn ligament in our study. Subluxation greater than 5 mm can be falsely negative with chronic tears of the ACL due to reattachment of the torn fibers by bridging fibrous tissue to the femur,[20] or when there is concomitantly displaced bucket-handle tear of the lateral meniscus blocks anterior subluxation of tibia.[20,29]

Relative posterior displacement of the lateral meniscus compared with the posterior cortical margin of the lateral tibial plateau has been described as a sign of increased anterior shift of tibia.[6,11,12] This "uncovered lateral meniscus sign" was reported to have respective sensitivity and specificity of 18% and 100%,[6] and 56% and 98.5%.[27] We reported the sensitivity, specificity, and accuracy of this sign to be 44%, 100%, and 83%, respectively. From many reports, this sign has been shown to have specificity approaching 100% in diagnosing complete ACL tear. However, its low sensitivity makes this sign of limited use.

Buckling of PCL occurs secondary to anterior subluxation of the tibia during positioning for imaging, resulting in an acute angulation of the normally smooth, convex posteriorly margin of PCL.[7] The assessment of PCL buckling is subjective, and was reported to have respective sensitivity, specificity, and accuracy of 17%, 100%, and 44%. Our study demonstrates higher sensitivity (87.5%) and accuracy (89%) but less specificity (90%) for this sign.

Our study concluded that, for primary sign of ACL tear, sagittal T2WI was the most accurate whereas coronal T1WI was the most specific sequence for diagnosing complete ACL tear. For secondary sign, anterior translation of tibia and uncovered lateral meniscus sign have 100% specificity, but the prior showed higher sensitivity and accuracy.

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