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# Anterolateral Subluxation of the Tibia Associated with Combined Anterior Cruciate and Medial Collateral Ligament Tears : MR Imaging of the Knee[1]

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**Purpose :** To evaluate the passive subluxation of the tibia on MR images in patient with both anterior cruciate ligament (ACL) and medial collateral ligament (MCL) tears and to demonstrate the usefulness of its measurement.

**Materials & Methods :** The authors performed a retrospective study of 123 knees with tears of both ACL (complete, n=70, partial, n=53) and MCL (complete, n=10, partial, n=113). ACL tears were documented at arthroscopy and MCL tears were interpreted by abnormal MR findings. One hundred normal knees were also studied for comparison. Using new internal landmarks, anterior subluxation was measured on an intercondylar sagittal image and lateral subluxation was measured on a mid-coronal image.

**Results :** Anterior subluxation of 3 mm or more was seen in 45/123(37%) abnormal knees, lateral subluxation of 3 mm or more in 20/123 (16%), and anterolateral subluxation in 15/123 (12%). Anterior subluxation of 5 mm or more was seen in 25/70 (36%) complete ACL tears, and no knees with partial ACL tears showed anterior subluxation of 5 mm or more.

**Conclusion :** Static anterolateral subluxation of the tibia occurs in knees with combined ACL and MCL tears, as measured on routine MR imaging. These measurements may help confirm the presence of ligament injuries and differentiate complete from partial ACL tear.

**Index Words :** Knee, injuries
Knee, ligaments, menisci and cartilage
Knee, MR

## INTRODUCTION

The anterior cruciate ligament (ACL) and medial collateral ligament (MCL) are the first and the second most frequently injured ligaments in the knee respectively (1, 2). Occurring together, these represent the most common combination of injuries of the static stabilizers of the knee (3—5). Many clinical and radiographic methods have been used to evaluate the status of knee ligaments based on tibial translation induced by the application of stress (6—8). On magnetic resonance (MR) imaging, anterior subluxation of the tibia has been indirectly assessed for the evaluation of ACL tears based on changes of the posterior cruciate ligament (PCL) curvature (9—12). Anterior translocation of the tibia, represented by tibial condylar displacement on the sagittal images, has been shown to be a reliable indicator of complete ACL tears (13, 14). The purpose of this study is to determine the degree and the frequency of anterior, lateral, and anterolateral subluxation of the tibia on routine MR images in patients with both ACL and MCL tears, and to demonstrate the usefulness of these measurements for differentiating normal from abnormal knees and complete from partial tears of the ACL.

## MATERIALS and METHODS

One hundred twenty three MR images of 123 patients with tears of both ACL and MCL were retrospectively reviewed. MR examinations were performed wi-

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thin 2 months after the injuries. ACL tears (70 complete, 53 partial) were confirmed by arthroscopy, performed within one month of the MR examination. Complete ACL tear was defined if the ligament was totally interrupted, while partial ACL tear was defined of at least some parts of the ligament having normal continuity macroscopically (15). MCL tears were interpreted on MR images by two of the authors (J.G.P and J.K.L). Complete MCL tear (n=10) was indicated by total disruption of the ligament or avulsion fracture at the site of attachment, while partial MCL tear (n=113) was indicated by high signal intensity within or surrounding the ligament, undulating contour, gross separation from the medial meniscus, or partial disruption (5, 16). For standard reference, 100 knees of 100 patients which appeared to be normal on MR images and showed no clinical evidence of ligament tears were also reviewed. Three patients were excluded because severe osteoarthritic changes or post fracture deformity in their knees caused significant distortion of the bony landmarks. The average age in the abnormal group was 34 years ranging from 15 to 66 years, and in the normal group the average age was 31 years ranging from 15 to 72 years.

MR imaging examinations were performed on a 1.0 Tesla superconducting system (Magnetom, Siemens, Erlangen, Germany) using the cylindrical transmit-receive extremity coil. The knee was positioned in extension with approximately 10 degree external rotation. Foam padding was placed around the knee to limit motion. There was no attempt to accentuate tibial subluxation during positioning. In all knees the following pulse sequences were used : A T1 weighted axial localizer (repetition time in milliseconds/echo time in milliseconds=250/15), coronal and sagittal proton density and T2 weighted images (1700~2000/20~80) with a 17 cm field of view, 192 × 256 matrix and 5 mm slice thickness without gap, and a three dimensional (3D) volume sequence with fast low angle shot (FLASH, 20~30/10, 15~30 degree flip angle, 0.7 mm slice thickness, 130 × 256 matrix with sagittal data acquisition).

Anterior subluxation of the tibia was measured on the spin echo sagittal image showing at least the distal half of the PCL. A line (anterior femorotibial line) was drawn from the most posterior point of the intercondylar notch of the femur to a point tangential to the most anterior superior portion of the intercondylar area of the tibia. A second line (posterior femorotibial line) was then drawn from the same point on the femur to a point tangential to the most posterior superior portion of the intercondylar area of the tibia (Fig. 1). These lines were measured by comparing them of the reference ruler on each image, then the posterior was subtracted from the anterior. Lateral subluxation of the tibia was measured on the most posterior spin echo coronal image showing bony connection between the femoral condyles. A reference line was drawn through the apex of the posterior tibial spine parallel to the long axis of the image. Lateral subluxation was defined as the distance from this line to a line drawn parallel to it and tangential to the medial cortex of the lateral femoral condyle in the concave region (Fig. 2). The degree of anteroposterior and mediolateral tibial subluxation was measured in millimeters and the results from the two observers were averaged, and then rounded to the nearest integer.

## RESULTS

On the intercondylar sagittal images of 100 normal knees, 61 knees showed no anterior or posterior sub-

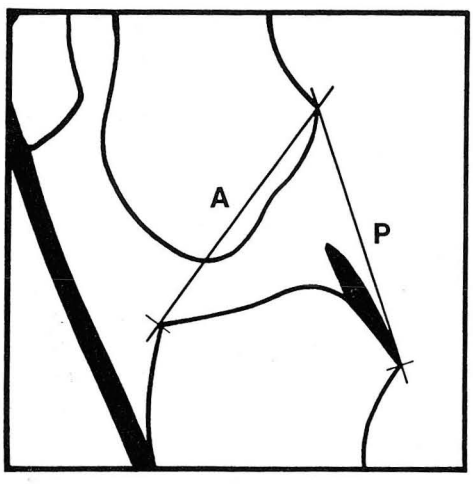


**Fig. 1.** Measurement method of anterior tibial subluxation. Anterior subluxation is defined as the difference between the lengths of the anterior (A) and posterior (P) femorotibial lines on the sagittal MR image showing the distal portion of the PCL.

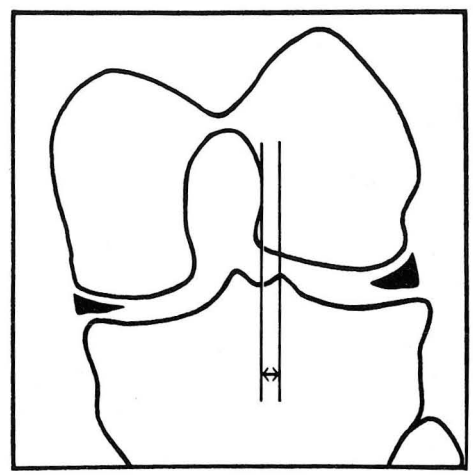

**Fig. 2.** Measurement method of mediolateral tibial subluxation. Subluxation is measured as the distance between vertical lines drawn through the posterior tibial spine and through the mid-medial border of the lateral femoral condyle on the most posterior coronal MR image showing intercondylar bone.

**Table 1.** Differences in the Length between the Anterior and Posterior Femorotibial Lines on Intercondylar Sagittal Image.

| Difference (mm) | Normal n=100 | Abnormal n=123 | with Complete ACL Tear 70/123 | with Partial ACL Tear 53/123 |
|---|---|---|---|---|
| −5 | 0 | 1 | 1 | 0 |
| −4 | 4 | 0 | 0 | 0 |
| −3 | 7 | 0 | 0 | 0 |
| −2 | 7 | 1 | 1 | 0 |
| −1 | 13 | 5 | 1 | 4 |
| 0 | 61 | 48 | 18 | 30 |
| 1 | 6 | 13 | 5 | 8 |
| 2 | 2 | 10 | 7 | 3 |
| 3 | 0 | 10 | 5 | 5 |
| 4 | 0 | 10 | 7 | 3 |
| 5 | 0 | 8 | 8 | 0 |
| 6 | 0 | 5 | 5 | 0 |
| 7 | 0 | 5 | 5 | 0 |
| 8 | 0 | 1 | 1 | 0 |
| 9 | 0 | 1 | 1 | 0 |
| 10 | 0 | 2 | 2 | 0 |
| 11 | 0 | 1 | 1 | 0 |
| 12 | 0 | 2 | 2 | 0 |

Note : Negative indicates posterior and positive indicates anterior subluxation.

**Table 2.** Lateral and Medial Tibial Subluxation in Normal and Abnormal Knees.

| Subluxation(mm) | −5 | −4 | −3 | −2 | −1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Normal(n=100) | 0 | 0 | 0 | 7 | 8 | 80 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Abnormal(n=123) | 1 | 0 | 2 | 10 | 12 | 60 | 10 | 8 | 7 | 7 | 4 | 1 | 0 | 1 |

Note : Negative indicates medial and positive indicates lateral subluxation.

luxation, while 28 showed subluxation in the range of −2 mm to 2 mm. No normal knees showed 3 mm or more of anterior subluxation. The mean anterior subluxation in the normal group was −0.5 mm ±0.2(±2 standard errors). Of 123 knees with tears of both the ACL and MCL, 45 knees (37%) showed anterior subluxation of 3 mm or more. Of those, 37 had complete ACL tears while eight had partial tears. Anterior subluxation of 5 mm or more was seen in 25/70 knees with complete ACL tears. All knees with partial ACL tears had anterior subluxation less than 5 mm (Table 1). The mean anterior subluxation of the 123 knees in the abnormal group was 2.1 mm ±0.5. The 53 knees with partial ACL tears showed anterior subluxation of 0.7 mm ±0.4, while the 70 knees with complete ACL tears showed anterior subluxation of 3.2 mm ±0.8. There was a statistically significant difference in anterior subluxation between normal and abnormal knees and between knees with partial and complete ACL tears (Wilcoxon Rank Sum test $p<.001$).

On the coronal images of 100 normal knees, 80 knees showed no medial or lateral subluxation, while 20 had −2 to 2 mm of subluxation (minus indicates medial subluxation). The mean lateral subluxation in the normal group was −0.1 mm ±0.1. Of the 123 abnormal knees, 20 knees (16%) showed lateral subluxation of the tibia of 3 mm or more and three knees (2%) showed medial subluxation of 3 mm or more. The mean lateral subluxation in the abnormal group was 0.5 mm ±0.3 (Table 2). Of those, the 113 knees with partial MCL tears showed lateral subluxation of 0.4 mm ±0.3, while 10 knees with complete tears showed 1.4 mm ±1.7. There was a statistically significant difference in lateral subluxation between normal and abnormal knees (Wilcoxon Rank Sum test $p<.01$).

Fifteen of the 123 abnormal knees (12%) demonstrated anterolateral subluxation with both anterior and lateral subluxation of 3 mm or more (Fig. 3). Each of these 15 knees had complete ACL tears and of these 13 had partial and two had complete MCL tears. One case showed anteromedial subluxation of the tibia with both anterior and medial displacement of 3 mm or more, in which the ACL and MCL were completely torn.

Anterior tibial subluxation of 3 mm or more distinguished the abnormal from the normal group with a sensitivity of 37% (15% with partial, 53% with complete ACL tears), a specificity of 100% (100%, 100%), and an

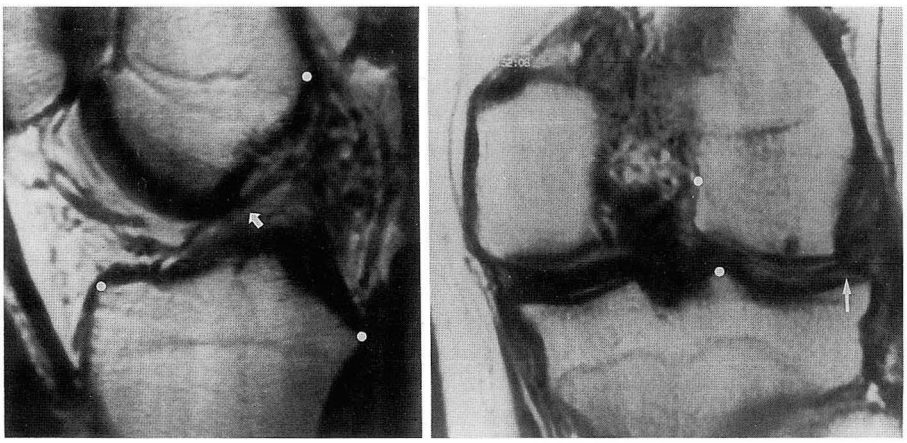

**Fig. 3.** Anterolateral subluxation of the tibia in a left knee with tears of the ACL and MCL.
a. Intercondylar sagittal image (2000/30). The anterior femorotibial line (between upper and anterior white dots) is much longer than the posterior femorotibial line (between upper and posterior white dots), denoting anterior subluxation of the tibia. An ACL tear is seen (arrow).
b. Coronal image (2000/30). The posterior tibial spine (lower white dot) shows considerable lateral displacement with respect to the plane of the medial border of the lateral femoral condyle (upper white dot), denoting lateral subluxation of the tibia. Tear of the lateral meniscus (arrow) is seen.

accuracy of 65% (71%, 81%). Lateral tibial subluxation of 3 mm or more distinguished the abnormal from the normal group with sensitivity of 16% (15% with partial, 30% with complete MCL tears), a specificity of 100% (100%, 100%), and an accuracy of 54% (55%, 94%).

## DISCUSSION

Instability of the tibia may occur in the knee, as in other joints, due to insufficiency of the static stabilizers. ACL-MCL injury is the most common combination of the complex ligament injuries (3—5). Common mechanisms of this injury are internal rotation of the tibia with valgus stress, external rotation of the tibia with valgus stress, and valgus stress (2, 4, 5). Because of anterior stability of the knee provided by the ACL and partly by the MCL, and medial stability provided by the MCL and partly by the ACL, simultaneous injury to the ACL and the MCL adversely affects the healing of both (17). After the ligament is torn by significant displacement, rotation, and/or angulation of the tibia with respect to the femur, the tibia might be returned to normal position by other tensile soft tissue structures (5). The failure of complete return of the displaced tibia to the normal position results in subluxation.

Physical examination with manual or mechanical stress and stress radiographs have been used to evaluate the function of knee ligaments (6—8). Anterior subluxation has been measured on lateral radiograph during stress in an attempt to identify tear of the ACL (8), and lateral subluxation of the tibia has been measured on standing anteroposterior radiograph to evaluate instability of the knee in patients with osteoarthritis (6).

More recently, subluxation of the tibia has been identified on MR images as a secondary sign of ACL tear (9—14). Kaye(8) has suggested that although secondary signs of ACL tear may help in certain diagnostic situations, specificities of 89—100% have been reported for detection of ACL tears on MR imaging without resorting to the use of secondary indicators (9, 19, 20). He did consider that findings such as anterior translation of the tibia could, when present, heighten the search for and engender more confidence in the diagnosis of ligamentous injuries. It was suggested that they might be useful in distinguishing partial from complete ACL tears.

Our method for measuring anterolateral subluxation is based on landmarks found in the intercondylar region of the knee. In this way, anteroposterior and mediolateral subluxation of the tibia could be measured more adequately. We found statistically significant passive anterior and lateral subluxation of the tibia in patients with combined ACL and MCL tears on routine MR imaging of the knee. Fifteen knees in the abnormal group demonstrated both anterior and lateral subluxation of 3 mm or more suggesting anterolateral instability.

Partial ACL tears represent 10—43% of all ACL tears (21, 22). Partial tears should be differentiated from complete tears because treatment is occasionally different for partial tear versus complete tear (22, 23). Murphy et al (5) found signal abnormalities of the lateral femoral or tibial condyles in all of 32 knees with acute complete ACL tears, and one of the six knees with acute partial ACL tears. This finding might not be useful in chronic complete ACL tears, however. We found a statistically significant difference in the incidence of anterior subluxation between the partial and complete ACL tear groups. Anterior tibial subluxation of 5 mm or more was seen in 25/70 complete ACL tears. No knees with partial ACL tears showed anterior tibial subluxation of 5 mm or more. Tears of the ACL and MCL lead to anterolateral subluxation which may be elicited and measured on routine MR imaging of the knee. Based on the presence and severity of subluxation, knees with torn ligaments can be more confidently differentiated from normal, and complete tears of ACLs can be better differentiated from partial tears.

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# 전방십자인대와 내측부인대 파열에 의한 경골 전외측 아탈구:MR 소견[1]

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**목 적**:전방십자인대와 내측부인대가 함께 파열된 환자에서 MR로 경골의 수동적 아탈구를 평가하고 이들 측정치의 유용성을 알아보고자 하였다.

**대상 및 방법**:전방십자인대 파열(완전 파열 70예, 부분 파열 53예)과 내측부인대 파열(완전 파열 10예, 부분 파열 113예)이 동반된 슬관절 123예와 정상 슬관절 100예를 대상으로 하였다. 전방십자인대 파열은 관절내시경으로 확진되었고 내측부인대 파열은 MR소견으로 판정되었다. 새로운 방법으로 시상면에서 전방 아탈구를, 관상면에서 외측 아탈구를 측정하였다.

**결 과**:인대 파열이 있는 총 123 슬관절 중 45예(37%)에서 3mm 이상의 전방 아탈구를, 20예(16%)에서 3mm 이상의 외측 아탈구를, 그리고 15예(12%)에서 전외측 아탈구를 보였다. 5mm 이상의 전방 아탈구는 전방십자인대 완전 파열이 있는 70예의 슬관절 중 25예(36%)에서 관찰되었으나 부분 파열이 있는 슬관절에서는 관찰되지 않았다.

**결 론**:전방십자인대와 내측부인대가 함께 파열된 슬관절에서 경골의 수동적 아탈구가 초래될 수 있으며 이는 기본 슬관절 MR검사에서 측정할 수 있다. 아탈구의 측정은 인대 손상의 진단에 도움을 주고 전방십자인대의 부분 파열과 완전 파열을 감별하는데 도움을 준다.