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Assessment of the anterolateral ligament of the knee by 1.5 T magnetic resonance imaging

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Abstract

Objective: This study was performed to evaluate the visibility of the knee's anterolateral ligament (ALL) by magnetic resonance (MR) imaging when evaluating injuries of the ALL in relation to injuries of the anterior cruciate ligament (ACL).

Methods: Two reviewers retrospectively analyzed MR images for the visibility and dimensions of the ALL and the relationship between ALL and ACL injuries. The intraclass correlation coefficient (ICC) and kappa analysis were used to assess interobserver reliability. The chi-square test was used to assess the relationship between ALL and ACL injuries.

Results: The entire ALL was viewed on 82% of all MR images. The ICC for ALL visualization ranged from moderate to perfect between the two readers. There was almost perfect agreement between the reviewers when evaluating ALL dimensions. The mean length $\pm$ standard error, median thickness, and mean width $\pm$ standard error of the ALL were 36.5 ± 0.6 mm, 2.5 mm, and 8.2 ± 0.2 mm, respectively. A statistically significant relationship was observed between ALL and ACL injuries.

Conclusion: The ALL was visible on most MR images, allowing ALL injuries to be noted during routine MR image interpretation. Radiologists should note concomitant ACL and ALL injuries as part of their assessments.

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Keywords
Knee, anterolateral ligament, Segond, injury, magnetic resonance imaging, anterior cruciate ligament

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Introduction

The anterolateral ligament (ALL) of the knee was first described in the literature by Segond in 1879.[1,2] However, whether this ligament comprised part of the iliotibial band or lateral collateral ligament of the knee remained unclear. Indeed, this structure had been named the "short lateral ligament,"[3] the "capsule-osseous layers of the iliotibial band,"[4–6] the "mid third lateral capsular ligament,"[7] and the "lateral capsular ligament"[8] by various researchers. Vieira et al.[9] eventually coined the term "anterolateral ligament" for this structure. Today, some authors accept that the ALL is a distinct ligament that originates from the lateral femoral epicondyle, very near the fibular collateral ligament, before coursing obliquely to insert in the anterolateral side of the tibial plateau, just posterior to Gerdy's tubercle.[10,11] Although the biomechanical properties of the ligament remain unclear, its role as a lateral stabilizer has been demonstrated.[1,11,12] Recently published studies have also suggested that the ALL may be visible on magnetic resonance (MR) images.[13–17] This is notable because some researchers view this structure as increasingly important due to the association between ALL and anterior cruciate ligament (ACL) injuries.[15,18,19]

The purpose of this study was to evaluate the visibility and anatomical features of the ALL and reveal the relationship between ALL and ACL injuries on 1.5 T MR images. To the best of our knowledge, no studies have simultaneously evaluated the visibility of each portion of the ligament separately, the dimensions of the ligament, and the relationship between ALL and ACL injury by routine 1.5 T MR imaging sequences with such large numbers of MR images as in the present study. We examined the interobserver differences between two observers who assessed the partial or total visibility and measured the dimensions of the ALL.

Materials and methods

Patients

Our institutional ethics committee approved this retrospective case-control study. The ethics committee waived the requirement for written informed consent due to the study design. We reassessed all knee MR images of patients who had undergone knee MR imaging from February 2016 to April 2017. Motion artifact was an exclusion criterion. A history of knee infection and septic arthritis were considered exclusion criteria, but no patients had either of these two conditions. The indications for knee MR imaging were trauma, knee pain, symptoms of meniscal injury, physical examination findings consistent with ACL injury, symptoms of osteoarthritis, limited range of motion, patellar dislocation, knee crepitation, and knee locking. The images of all patients who had undergone knee MR imaging within the time interval of this study were reassessed.

Data source and MR imaging protocol

All MR images were evaluated and accessed using the picture archiving and communication system at our institution. MR scans were performed in our hospital using a 1.5 T system (Magnetom Essenza; Siemens, Erlangen, Germany) with an eight-channel knee coil. Sagittal T1-weighted images were taken with the following settings: repetition time (TR), 515 ms; echo time (TE), 14 ms; matrix, 192×256; field of view (FOV), 160 mm; slice thickness, 3.5 mm; interslice gap, 0.7 mm; echo train length (ETL), 55; and number of excitations (NEX), 2. Axial proton density-weighted (PDW) images were taken with the following settings: TR, 2,500 ms; TE, 28 ms; matrix, 206×256; FOV, 170 mm; slice thickness, 3.5 mm; interslice gap, 0.7 mm; ETL, 69; and NEX, 1. Coronal PDW images were taken with the following settings: TR, 2,350 ms; TE, 26 ms; matrix, 205×256; FOV, 180 mm; slice thickness, 3.5 mm; interslice gap, 0.7 mm; ETL, 69; and NEX, 1. Sagittal PDW images were taken with the following settings: TR, 2,670 ms; TE, 24 ms; matrix, 205×256; FOV, 190 mm; slice thickness, 3.5 mm; interslice gap, 0.7 mm; ETL, 70; and NEX, 1. Images were obtained for all knee MR imaging examinations, which were performed at 15 degrees of knee joint flexion. Coronal sequences were oriented parallel to the femoral condyles.

MR imaging interpretation

Two radiologists (a musculoskeletal radiologist with 11 years of experience and a general radiologist with 20 years of experience) independently reviewed all knee MR images according to visibility and dimensional measurements. The reviewers had previously evaluated 29 knee MR images that were not included in this study and measured the dimensions together to improve conformity. Based on previous anatomic studies,[1,11,20,21] the ALL was divided into femoral (from the origin to the bifurcation point), meniscal (from the bifurcation point to the meniscal insertion), and tibial (from the bifurcation to the tibial insertion) parts. Visibility was then interpreted according to these anatomical parts, and each reviewer independently indicated whether the parts were visible. The researchers also indicated whether the entire ligament was visible. If any part was not seen in both coronal and axial MR imaging planes, it was considered "not visible." Measurements were independently performed by each reviewer only if the entire ligament was visible. Anatomical measurements of length, width, and thickness were performed as described by Taneja et al.[16] (Figure 1). The axial plane at the level of the popliteal groove in the lateral femoral condyle was chosen to measure width and thickness. After a blind review of the visibility and anatomical measurements of the ALL, the two reviewers evaluated the ALL with respect to injuries and whether a concomitant ACL injury was present if the entire ligament was visible. Focal or diffuse thickening, high signal intensity in the PDW images, disruption, or an irregular contour of the ligament was accepted as injury of the ALL. Thickening of the ligament, increased signal intensity on PDW images, discontinuity of the fibers, and changes in the expected course of the ACL (should be as steep or steeper than the intercondylar roof, with the apex pointing posteriorly and less steep than Blumensaat's line) were accepted as primary signs of ACL rupture. For overall determination of ACL injury, these primary signs were then evaluated with secondary signs such as bony contusions of the posterolateral tibial plateau and lateral femoral condyle, Segond fracture, anterior tibial translocation sign, reduced posterior cruciate ligament angle, positive posterior cruciate ligament line, and uncovered posterior horn of the lateral meniscus.[22–28] ALL and ACL injuries were evaluated together by the two reviewers, and the results were interpreted by consensus between the reviewers.

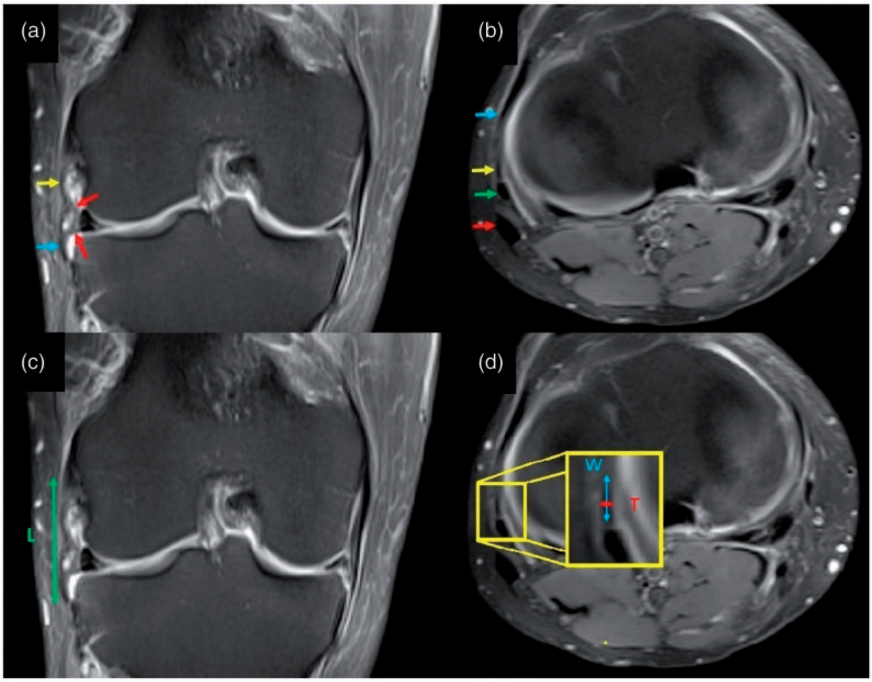

Figure 1. Representative fat-saturated proton density-weighted coronal (left) and axial (right) magnetic resonance images without ligament injury. (a) In the coronal plane, the femoral part (yellow arrow), the meniscal part (red arrows), and the tibial part (blue arrow) of the anterolateral ligament is observed. (b) In the axial plane, the iliotibial band (blue arrow), the anterolateral ligament (yellow arrow), the lateral collateral ligament (green arrow), and the biceps femoris tendon (red arrow) are indicated. Measurements of the (c) length and (d) thickness and width of the anterolateral ligament are shown.

Statistical analysis

Interobserver reliability was tested by intraclass correlation coefficients (ICCs) and kappa analyses, using the visibility and measurement values. Kappa values were interpreted as shown in Table 1. The relationship among ALL length, width, and injury was tested by an independent-samples *t*-test. The Mann–Whitney *U* test was used to compare the relationship between ALL thickness and injury. The relationship between ALL and ACL injuries was assessed by the chi-squared test. The Kolmogorov–Smirnov test was used to reveal the homogeneity of the data distribution. According to the Kolmogorov–Smirnov test, the data distribution of the ALL thickness for both observers and the ALL length for Observer 2 were not homogenous; therefore, medians rather than means and standard errors are reported (Table 2). All statistical analyses were performed using MedCalc Version

Table 1. Interpretation of intraclass correlation coefficients for interobserver agreement.

Kappa value	Level of agreement
0.00–0.20	None
0.21–0.39	Minimal
0.40–0.59	Weak
0.60–0.79	Moderate
0.80–0.90	Strong
>0.90	Almost perfect

Table 2. Magnetic resonance imaging measurements of the anterolateral ligament by each observer

Dimensions	Observer 1	Observer 2
Length (mm)	36.5 ± 0.6	36.6
Thickness (mm)	2.5	2.48
Width (mm)	8.2 ± 0.2	8.2 ± 0.2

Data are presented as median or mean ± 2× standard error.

17.6 (MedCalc Software, Ostend, Belgium), and p-values of <0.05 were considered statistically significant.

Results

Participants

In total, 209 consecutive knee MR images of 171 patients were reassessed during the study period. Three knee MR images of three patients were excluded because of motion artifacts. Therefore, 206 knees of 168 patients (87 men, 81 women) were included in this study. The mean age of the patients was 40.47 ± 13.38 years for all patients, 37.61 ± 13.23 years for men, and 43.00 ± 12.98 years for women. In total, 104 left knees and 102 right knees were assessed in this study. Thirty-nine patients underwent knee MR imaging for assessment of trauma, 36 for knee pain, 34 for symptoms of meniscal injury, 19 for physical examination findings consistent with ACL injury, 19 for symptoms of osteoarthritis, 10 for limited range of motion, 6 for suspected patellar dislocation, 3 for knee crepitation, and 2 for knee locking. Sixty-eight patients had radiographic findings of osteoarthritis such as joint space narrowing, osteophyte formation, subchondral sclerosis, cartilaginous defects, or bone marrow edema.[29–31] ACL rupture was observed in 112 of the 206 MR images.

Table 3. Visibility of the anterolateral ligament with respect to its anatomical parts

	Observer 1 (n = 206)	Observer 2 (n = 206)
Entire ligament	169 (82.0)	169 (82.0)
Femoral part	185 (89.8)	184 (89.3)
Meniscal part	182 (88.3)	183 (88.8)
Tibial part	180 (87.4)	179 (86.9)

Data are presented as n (%) of magnetic resonance imaging examinations.

Visualization of the ALL

The entire ALL was visible on 169 (82%) knee MR images (Table 3). The ALL was characterized best as a thin ligament in the coronal plane, was located on the lateral side of the knee, and was surrounded by synovial fluid or adipose tissue. The length of the ALL was measured in the coronal plane, and the width and thickness were measured in the axial plane. The sagittal plane was sometimes helpful, but the coronal and axial planes on PDW images were most useful for visualization and anatomical measurements (Figure 1).

The interobserver agreement for ALL visualization was almost perfect for the femoral and tibial parts, with the ICC analysis indicating perfect agreement for the entire ligament and moderate agreement for the meniscal portion of the ALL. Considering the ALL dimensions, almost perfect interobserver agreement between the reviewers was attained (Table 4). The MR imaging measurements of the ALL with respect to the data distribution properties are presented in Table 2.

ALL and ACL injuries

Of the 169 knee MR images on which the entire ligament was seen, 90 (53.3%) had ALL injuries; additionally, 112 of the 206 MR images had evidence of ACL injuries. There was a statistically significant relationship between ALL and ACL injuries ($p < 0.001$) (Figure 2), but not between the presence of ALL injuries and the different ligament dimensions of the ALL. In the investigation of the relationship between dimensional measurements and ALL injury, the p-values for length, thickness, and width were 0.40, 0.36, and 0.75, respectively.

Discussion

We analyzed the ALL as if it were component of routine knee MR imaging evaluation, similar to assessment of the ACL or collateral ligaments. Our results showed that the ALL was entirely visible on 82% of the MR images, that the ligaments' dimensions were verifiable, and that the reviewers could demonstrate a relationship between ALL and ACL injuries.

The ALL functions as a lateral stabilizer of the knee, but its contribution to knee biomechanics is not fully understood.[1,11,12,32] Claes et al.[11] hypothesized that the ALL controls tibial rotation and thereby affects the pivot-shift phenomenon. Dodds et al.[12] also showed that the length of this ligament increased when applying an internal rotation torque of 5 Nm, which emphasizes the role of the ALL in generating resistance to internal rotation.

The contribution of the ALL to rotational stability has also been investigated in relation to the ACL. The results of some studies suggest that persistent rotational instability and pivot-shift were present in up to 10% of ACL-reconstructed knees,[1,12,33–35] which might explain the failures after technically successful ACL reconstructions. Song et al.[18] suggested that the presence and severity of lateral bone

Table 4. Interobserver agreement (kappa values from statistical analysis)

Visibility	
Femoral part	0.949
Meniscal part	0.784
Tibial part	0.978
Entire ligament	1
Dimensions	
Length	0.996
Thickness	0.994
Width	0.997

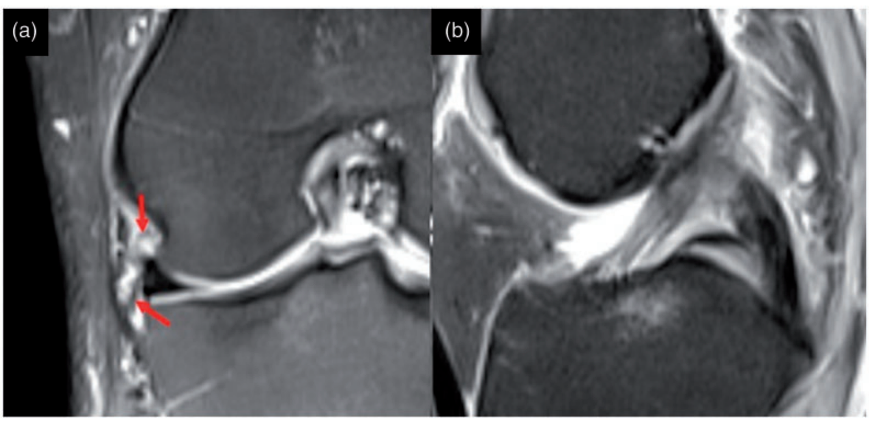

Figure 2. Representative fat-saturated proton density-weighted magnetic resonance images showing ligament injury. (a) In the coronal plane, the meniscal components of the anterolateral ligament were partially disrupted and torn, as shown by the red arrows. (b) The same patient's sagittal magnetic resonance images revealed a partial anterior cruciate ligament tear.

contusions after acute noncontact ACL injuries were related to ALL abnormalities, high-grade pivot-shift, and concomitant meniscal lesions. In cadaveric knees, Spencer et al.[36] suggested that internal rotation during the simulated early-phase pivot-shift test was significantly different between ALL-intact and ALL-sectioned knees with fully sectioned ACLs. They explained the role of the ALL in controlling anterolateral laxity and the composite effect of lateral extra-articular tendinosis in governing both anterior and rotational laxity.[36]

In 1879, Paul Segond was the first researcher to identify avulsion fracture of the proximal lateral tibia caused by forced internal rotation of a flexed knee.[2] Disruption of the ACL was included in this definition, but at that time, the ALL had not been described as a distinct structure. Although several authors had given different names to the structure that attached to the Segond fragment,[3–8] it was Claes et al.[37] who concluded that the ALL was attached to the exact location mentioned in the Segond fracture.

Some studies have evaluated the presence and dimensions of the ALL on MR imaging. For example, Helito et al.[13] assessed 33 knees by 1.5 T MR imaging but reported that the entire ligament was only visible in 33.3% of images. The researchers in that study claimed that coronal sequences were the best imaging planes with which to view the ALL, that the tibial portion of the ligament was the least often identified part, and that the meniscal portion was the most easily identified part.[13] In another study by Helito et al.,[14] 39 knees were assessed by 1.5 T MRI and the results suggested that PDW images and T2-weighted, fat-saturated MR images in the coronal plane were the best for visualizing the ALL. Using this method, the ALL was visualized entirely on 71.7% of MR images and at least a part of the ligament was characterized on 97.4% of MR images. In that report, the meniscal part was the most often visualized and the tibial part was the least often identified.[14] Taneja et al.[16] also interpreted 70 knee MR images but only visualized the ALL in 51%. However, they reported length, thickness, and width dimensions of 33.0, 1.9, and 5.6 mm, respectively.[16] In the present study, the femoral part was most visible and the tibial part was relatively harder to visualize. The origin of the ALL was also difficult to determine because of the close proximity of the origin of the lateral collateral ligament. The meniscal part was particularly difficult to distinguish between rupture and nonvisualization because it was such a small component. The femoral portion of the ALL was most often visualized, and the interobserver agreement was only moderate for the meniscal part. In addition, the length, thickness, and width dimensions were 36.5, 2.5, and 8.2 mm, respectively.

Concerning the relationship between ACL and ALL injuries, Claes et al.[38] evaluated 206 knees of patients who had undergone surgery and reported that 77.8% of the knees treated by ACL reconstruction had radiological ALL abnormalities. Song et al.[18] also found that 38.9% of patients who had undergone ACL reconstruction had evidence of ALL abnormalities on preoperative MR images. They reported that the presence and severity of lateral bony contusions of the knee were significantly associated with ALL abnormalities in patients with acute noncontact ACL injuries. In the current study, we confirmed that a statistically significant relationship exists between ACL and ALL injuries ($p < 0.05$), but we found no relationship between the presence of ALL injuries and the ALL dimensions.

However, some researchers claim that the ALL may not be a "distinct" ligament and might instead be a part of other structures of the lateral region of the knee. Some researchers have asserted that the ALL is a capsular thickening rather than a separate ligament,[39,40] whereas other authors have claimed that this structure is part of a larger complex called the "anterolateral structures."[41] In addition, some researchers have concluded that standard 1.5 T MR sequences of ALL tears cannot distinguish between a torn or intact ALL.[15]

This study has several limitations that should be mentioned. First, despite undertaking a pilot review to improve evaluation of the ALL, the researchers had little training in evaluating the ALL by MR imaging because it is not a routine imaging parameter. Second, in some patients with ALL injury, the measurements of the ligament dimensions could have been affected by rupture or disruption of the fibers. Third, although the ACL injuries were assessed by consensus between the two experienced reviewers, ACL and ALL injuries were determined by MR imaging; however, surgical results would be more precise in confirming the presence of ligament injury.

Overall, although the presence and functional role of the ALL remains controversial, the literature provides important information regarding the role of this ligament in functional stability and the visibility of the ALL on MR images. We conclude that the ALL is visible in most knee MR imaging examinations with 1.5 T MR machines and that ALL injuries are related to ACL injuries.

Author contributions

Guarantor of integrity of entire study: VK
Study concepts: VK, HA, GRU
Study design: VK, HA, AKS, TÇ
Data acquisition: VK, TÇ, GRU
Data analysis: VK, TÇ
Statistical analysis: AKS, VK
Image interpretations: VK, TÇ
Literature research: VK, HA, GRU, AKS, TÇ
Manuscript drafting: VK, HA
Manuscript editing: VK, AKS, HA, TÇ, GRU

Declaration of conflicting interest

The authors declare that there are no conflicts of interest.

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