Can the Anterolateral Ligament Be Reliably Identified in Anterior Cruciate Ligament–Intact and Anterior Cruciate Ligament–Injured Knees on 3-T Magnetic Resonance Imaging?

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Background: The anterolateral ligament (ALL) has been described as an extracapsular stabilizer of knee rotational stability. Investigators have shown a renewed interest in the ALL and further evaluated its anatomy and biomechanical role as a knee stabilizer. The appearance of the ALL on magnetic resonance imaging (MRI) remains inconsistent across the literature.

Purpose: The aims of this study were 2-fold. The first objective was to further investigate the appearance of the uninjured ALL on MRI and provide data regarding interrater agreement in identifying the ligament. The second objective was to describe the incidence of concomitant ALL injuries in anterior cruciate ligament (ACL)–injured knees and provide data regarding interrater agreement in identifying and grading these injuries.

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

Methods: Fifty consecutive MRI scans of non–ACL-injured knees (control) and 50 consecutive MRI scans of ACL-injured knees performed at a single sports medicine center were identified. Three musculoskeletal radiologists independently reviewed the MRI scans in a randomized and blinded fashion. In the control group, the reviewers classified the ALL as visualized or not and did so for the proximal, middle, and distal thirds of the ligament. In the ACL tear group, the reviewers classified the ALL as visualized or not for each third of the ligament. They noted whether the ligament was injured and graded the injury as low, intermediate, or high.

Results: All 3 segments of the ALL were visualized in a mean 11% of patients. The ALL was partially visualized in a mean 68% of patients. The distal third of the ALL was injured 28% (14/50) of the time in the ACL tear group. The agreement rate among raters for classifying the injury status was fair to poor.

Conclusion: Visualization of the ALL was inconsistent in the current study. Identifying and grading an injury to the ALL were difficult and had poor interobserver agreement. Using MRI to aid in the diagnosis of an ALL injury in the setting of an ACL tear is unreliable according to our study results. Further research looking at consistent ALL identification and injury patterns should be undertaken.

Keywords: anterolateral ligament; anterior cruciate ligament; MRI

The anterolateral ligament (ALL) has been mentioned in the literature in years past as an extracapsular stabilizer of knee rotational stability.[11] More recently, investigators have shown a renewed interest in the ALL and further described its anatomy and biomechanical role as a knee stabilizer.[5,6,13] It has been hypothesized that an injury to the ALL occurs in high frequency with concomitant anterior cruciate ligament (ACL) tears.[5] Ferretti et al[8] reported lateral-sided capsular injuries in up to 90% of patients at the time of ACL surgery. The true incidence of this combined injury pattern is unknown.

The gross anatomy of the ALL has been well characterized. Claes et al[6] dissected 41 cadaveric knees and found that the ALL was present in 97% of specimens. They described the ligament as a well-defined structure, clearly distinguishable from the joint capsule. The origin of the ALL was at the prominence of the lateral epicondyle of the femur, just anterior to the lateral collateral ligament. The insertion of the ALL was found to be on the anterolateral tibia between the Gerdy tubercle and the tip of the

fibular head.[6] Kennedy et al[12] further characterized the anatomy of the ligament, identifying its femoral attachment site as 4.7 mm posterior and proximal to the lateral collateral ligament attachment and the tibial attachment as 24.7 mm posterior to the Gerdy tubercle.

The proposed biomechanical role of the ALL is to resist tibial internal rotation at middle and high degrees of knee flexion. Parsons et al[13] described the role of the ACL and ALL in a cadaveric study using superposition principles to measure in situ forces on each ligament. They found that the ALL was an important stabilizer of internal rotation at flexion angles greater than 35° but was minimally loaded with anterior drawer testing. The ACL was the primary restraint to anterior drawer testing at all flexion angles. Their conclusion was that an ALL-damaged knee could result in instability at high angles of flexion.[13] More recently, Spencer et al[14] performed a cadaveric study looking at the effect of ALL transection and subsequent reconstruction on knee kinematics. They found that ALL reconstruction did not significantly reduce internal rotation or anterior translation during simulated early-phase pivot-shift testing.[14]

The appearance of the ALL on magnetic resonance imaging (MRI) has been studied and remains inconsistent across the literature. Helito et al[11] reviewed 39 MRI scans of knees without cruciate ligament injuries to describe the path of the All in relation to the lateral knee structures. In that study, 2 radiologists reviewed 1.5-T MRI scans. They found that portions of the ALL were visualized 97.8% of the time but that the complete ligament was visible on only 71% of the scans.[11] In another study aimed at evaluating the visibility of the ALL using MRI, the ligament was visible only 51% of the time.[15] Similarly, the study used 1.5-T MRI, and scans were reviewed by musculoskeletal radiologists.

The aims of this study were 2-fold. One objective was to further investigate the appearance of the uninjured ALL on MRI and provide data regarding interrater agreement in identifying the ligament. The second objective was to describe the MRI incidence of concomitant ALL injuries in ACL-injured knees and provide data regarding interrater agreement in identifying and grading these injuries.

METHODS

After approval of the study by an institutional review board, 50 consecutive MRI scans of non–ACL-injured knees and 50 consecutive MRI scans of knees with previously confirmed ACL injuries performed at a single sports health center were identified. The exclusion criteria were patients who had high-grade ligament injuries to the medial collateral ligament, lateral collateral ligament, or posterior cruciate ligament and patients with lateral meniscus tears. Exclusion criteria were set to ensure the best uninjured views of the ALL in the control group and to capture knees with only ACL and ALL injuries in the ACL tear group, as one of the aims of this study was to report on the incidence. Lateral meniscus tears were excluded, as gross anatomic studies have described the intimate relationship of the lateral meniscus and the ALL.[6] We did not want to overestimate ALL injuries secondary to edema from associated meniscus lesions. All MRI examinations were performed on a single 3-T system (Verio; Siemens) with the standard protocol. The imaging protocol consisted of coronal and sagittal fat-saturated fast spin echo (FSE) proton density–weighted sequences, sagittal fat-saturated FSE T2-weighted and non–fat-saturated FSE intermediate-weighted sequences, a coronal non–fat-saturated FSE T1-weighted sequence, an axial fat-saturated FSE T2-weighted sequence, and a 3-dimensional fat-saturated FSE sequence. All MRI scans were reviewed on a research PACS system (TeraRecon).

Three fellowship-trained musculoskeletal radiologists (N.S., J.P., C.W.) independently reviewed the MRI scans in a randomized order and were blinded to the injury group and blinded from the readings of the other readers. Before starting the formal review, the readers reviewed 10 MRI scans in consensus to agree on the appearance of the ALL and grading the ALL injury. These 10 MRI scans were selected at random from a control group. The grading system was as follows. In the control group, the reviewers classified the ALL as visualized or not visualized and did so for the proximal, middle, and distal thirds of the ligament. The proximal ligament was defined as that portion of the ligament coursing from the femoral attachment to the level of the lateral meniscus. The middle portion was at the level of the lateral meniscus. The distal portion was between the lateral meniscus and tibial attachment. In the ACL tear group, the reviewers again classified the ALL as visualized or not visualized for each third of the ligament. In addition, they noted whether the ligament was injured and graded the injury as low (intact ligament with increased T2 signal adjacent to the ligament but not within the ligament), intermediate (increased T2 signal within the ligament without complete disruption of the ligament), or high (complete disruption of the ligament). Study data were collected and managed using REDCap.[10]

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TABLE 1
Patient Demographics[a]

	Total (N = 100)	ACL Tear Group (n = 50)	Control Group (n = 50)
Age, mean ± SD, y	21.6 ± 7.6	21.1 ± 7.1	22.1 ± 8.0
Male sex, n (%)	47 (47)	26 (52)	21 (42)

[a]ACL, anterior cruciate ligament.

TABLE 2
Visualization of All 3 Segments of the ALL[a]

	Total (N = 100)	ACL Tear Group (n = 50)	Control Group (n = 50)
Rater 1			
Not visualized	89 (89)	42 (84)	47 (94)
Visualized	11 (11)	8 (16)	3 (6)
Rater 2			
Not visualized	78 (78)	36 (72)	42 (84)
Visualized	22 (22)	14 (28)	8 (16)
Rater 3			
Not visualized	99 (99)	50 (100)	49 (98)
Visualized	1 (1)	0 (0)	1 (2)
Average			
Not visualized	89 (89)	43 (86)	46 (92)
Visualized	11 (11)	7 (14)	4 (8)

[a]Values are shown as n (%). ACL, anterior cruciate ligament; ALL, anterolateral ligament.

Statistical Analysis

Categorical factors were described using frequencies and percentages, while continuous variables were summarized with means and SDs. Raw agreement was calculated overall and between pairs of raters. In addition to the overall agreement, the 95% CI was estimated. To measure chance-adjusted agreement, the Cohen kappa was used for pairs of raters, and the Light kappa for multiple raters was used to measure overall agreement. Weights were applied for severity measures to account for the degree of disagreement. Bias-corrected bootstrap 95% CIs were calculated for the Light kappa. Analyses were performed using R software (version 3.2). Measures of agreement were calculated using the irr[9] and psy[7] packages, and bootstrap 95% CIs were determined using the boot[1] package.

RESULTS

Patient Demographics

MRI scans from 50 patients with isolated ACL tears and 50 patients without any ligamentous injuries (control group) were reviewed. The mean age of the entire cohort was 21.6 years, with 47% being male (Table 1).

TABLE 3
Visualization of at Least 1 Segment of the ALL[a]

	Total (N = 100)	ACL Tear Group (n = 50)	Control Group (n = 50)
Rater 1			
None visualized	43 (43)	15 (30)	28 (56)
At least 1 visualized	57 (57)	35 (70)	22 (44)
Rater 2			
None visualized	28 (28)	9 (18)	19 (38)
At least 1 visualized	72 (72)	41 (82)	31 (62)
Rater 3			
None visualized	25 (25)	9 (18)	16 (32)
At least 1 visualized	75 (75)	41 (82)	34 (68)
Average			
None visualized	32 (32)	11 (22)	21 (42)
At least 1 visualized	68 (68)	39 (78)	29 (58)

[a]Values are shown as n (%). ACL, anterior cruciate ligament; ALL, anterolateral ligament.

Visualized ALL

Figure 1. T2-weighted coronal image of a left knee. ALL, anterolateral ligament.

Visualization of the ALL

All 3 segments (proximal, middle, and distal thirds) of the ALL were visualized in a mean 11% of patients (Table 2). The 3 segments of the ALL were visualized a mean 14% of the time in the ACL tear group versus 8% of the time in the control group. At least 1 of the 3 segments of the ALL was visualized in a mean 68% of patients (Table 3). At least 1 segment of the ALL was visualized in a mean 78% of the ACL tear group and 58% of the control group. An example of complete visualization of the ligament is shown in Figure 1.

Visualization Agreement

The raw agreement rate for visualizing the entire ligament (proximal, middle, and distal thirds) was 71%

TABLE 4
Visualization Agreement Among Raters[a]

Segment of ALL	n	Overall Raw Agreement, % (95% CI)	Overall Light Kappa (95% CI)
Entire ligament			
Total	100	71 (62 to 80)	0.048 (−0.020 to 0.130)
ACL tear group	50	62 (49 to 75)	0.029 (−0.053 to 0.130)
Control group	50	80 (69 to 91)	0.078 (−0.039 to 0.210)
Proximal			
Total	100	68 (59 to 77)	0.058 (−0.019 to 0.140)
ACL tear group	50	58 (44 to 72)	0.035 (−0.054 to 0.140)
Control group	50	78 (67 to 89)	0.110 (−0.034 to 0.230)
Middle			
Total	100	41 (31 to 51)	0.190 (0.081 to 0.300)
ACL tear group	50	36 (23 to 49)	0.210 (0.081 to 0.370)
Control group	50	46 (32 to 60)	0.130 (−0.012 to 0.330)
Distal			
Total	100	37 (28 to 46)	0.120 (0.024 to 0.240)
ACL tear group	50	46 (32 to 60)	0.130 (0.012 to 0.290)
Control group	50	28 (16 to 40)	0.065 (−0.087 to 0.220)

[a]ACL, anterior cruciate ligament; ALL, anterolateral ligament.

across all raters (Table 4). Raw agreement for visualizing the entire ligament was higher for the control group versus the ACL tear group (80% vs 62%, respectively). Raw agreement for visualization decreased from the proximal to the middle and distal segments. The raw agreement rate for visualization was 68% in the proximal segment, while agreement was under 50% for the other 2 segments. For chance-adjusted agreement using kappa statistics, values under 0.2 were considered poor, and values between 0.21 and 0.4 were considered fair. For visualization, agreement was fair only for the ACL tear group in the middle segment. In all other cases, agreement was poor (kappa <0.2).

Injury Prevalence

The ALL injury prevalence, accounting for all degrees of injury by segment, is shown in Table 5. The proximal third of the ALL was diagnosed as injured 6% of the time in all patients (10% in ACL tear group and 2% in control group). The middle third of the ALL was diagnosed as injured 11% of the time in all patients (22% in ACL tear group and 2% in control group). Last, the distal third of the ALL was diagnosed as injured 17% of the time in all patients (28% in ACL tear group and 6% in control group). An example of an injured ALL is shown in Figure 2.

Injury Agreement

The raw agreement rate among raters for classifying the injury status was 68%, 38%, and 21% for the proximal, middle, and distal segments of the ALL, respectively (Table 6). Raw agreement for classifying the injury status in the ACL tear group was lower than the control group for

TABLE 5
ALL Injury Prevalence by Segment
Averaged Across All Raters[a]

Segment of ALL	Total	ACL Tear Group	Control Group
Proximal			
Not visualized	87 (87)	42 (84)	45 (90)
Visualized, normal	7 (7)	3 (6)	4 (8)
Visualized, low-grade injury	3 (3)	3 (6)	0 (0)
Visualized, intermediate-grade injury	3 (3)	2 (4)	1 (2)
Visualized, high-grade injury	0 (0)	0 (0)	0 (0)
Middle			
Not visualized	63 (63)	28 (56)	36 (72)
Visualized, normal	25 (25)	12 (24)	13 (26)
Visualized, low-grade injury	6 (6)	6 (12)	1 (2)
Visualized, intermediate-grade injury	5 (5)	5 (10)	0 (0)
Visualized, high-grade injury	0 (0)	0 (0)	0 (0)
Distal			
Not visualized	36 (36)	14 (28)	22 (44)
Visualized, normal	48 (48)	22 (44)	26 (52)
Visualized, low-grade injury	10 (10)	9 (18)	1 (2)
Visualized, intermediate-grade injury	6 (6)	5 (10)	1 (2)
Visualized, high-grade injury	1 (1)	0 (0)	1 (2)

[a]Values are shown as n (%). The numbers are the average of 3 raters and were rounded to the nearest integer. ACL, anterior cruciate ligament; ALL, anterolateral ligament.

Injured ALL

Figure 2. T2-weighted coronal image of an injury to the anterolateral ligament (ALL) in a right knee.

all segments. Chance-adjusted agreement using kappa statistics was poor (kappa <0.2) in the proximal segment. Kappa values were mixed between poor (kappa <0.2) and fair (0.21 < kappa < 0.4) in the middle and distal segments.

TABLE 6
Injury Agreement Among Raters[a]

Segment of ALL	n	Overall Raw Agreement, % (95% CI)	Overall Light Kappa (95% CI)
Proximal			
Total	100	68 (59 to 77)	0.076 (−0.0086 to 0.18)
ACL tear group	50	58 (44 to 72)	0.076 (−0.038 to 0.2)
Control group	50	78 (67 to 89)	0.074 (−0.046 to 0.22)
Middle			
Total	100	38 (28 to 48)	0.29 (0.18 to 0.45)
ACL tear group	50	30 (17 to 43)	0.31 (0.18 to 0.48)
Control group	50	46 (32 to 60)	0.11 (−0.04 to 0.26)
Distal			
Total	100	21 (13 to 29)	0.28 (0.14 to 0.42)
ACL tear group	50	20 (9 to 31)	0.23 (0.035 to 0.44)
Control group	50	22 (11 to 33)	0.19 (0.017 to 0.42)

[a]ACL, anterior cruciate ligament; ALL, anterolateral ligament.

DISCUSSION

Visualization of the ALL on MRI is inconsistent across the literature. In our study using 3-T MRI with 3 musculoskeletal fellowship–trained radiologists, we report visualizing the entire ligament 11% of the time. Partial visualization of the ALL was reported 68% of the time in our series. The interrater agreement on ligament visualization was poor, with kappa values <0.2. This is similar to the findings reported by Taneda et al[15] in which 1.5- and 3-T MRI were used by 2 readers to look at 60 knees to evaluate ALL visibility. They reported complete visualization 11% of the time and partial visualization in 51% of knees. The kappa statistics for their study indicated higher interrater agreement on ligament identification, with a kappa value of 0.7.[15] Helito et al[11] reported a much higher rate of ligament identification. In their study of 42 knees using 1.5-T MRI and 2 readers, they reported identifying a portion of the ligament 97.8% of the time. The complete ligament was visualized 71.7% of the time, and there was high interobserver agreement, with kappa values ranging from 0.8 to 1.0.[10] There was higher interobserver agreement in the studies with only 2 readers. It is unclear why the variation in ligament visualization exists.

The incidence of ALL injuries in association with ACL tears is not well known. Some authors have reported lateral capsular injuries in up to 90% of ACL tears.[8] The data reported in our cohort suggest that the ALL is difficult to consistently identify on 3-T MRI in both ACL-injured and -uninjured knees. The interrater agreement in identification of the ligament is fair to poor, which makes identifying injuries to the ligament inconsistent. In our study, the distal third of the ALL was judged to be injured 28% of the time with a concomitant ACL tear. Agreement in classifying the injury status was poor, with kappa values <0.2.

This is in contrast to the findings of Claes et al,[4] who reported a 78.8% concomitant injury rate in a retrospective cohort study of 271 participants. The weaknesses of their cohort study were that the MRI scans reviewed were of differing qualities from various institutions around the country. Two orthopaedic surgeons reviewed the scans and classified the ALL as "normal," "abnormal," or "nonvisualized" and reported that the distal segment of the ALL was injured 77.8% of the time. There was no interobserver agreement rate reported.

One of the problems encountered was the ability to definitively distinguish the ALL from the fibular collateral ligament proximally and the iliotibial band distally because of partial volume averaging, which may have caused lower rates of visualization in these areas. In theory, 3-T MRI should improve detection because of a higher signal-to-noise ratio and possibly higher spatial resolution, but this did not bear out in this study. Other factors may improve detection: (1) oblique coronal imaging along the expected oblique course of the ALL; (2) 3-dimensional sequences that have higher through-plane spatial resolution, which would allow reformatting in an oblique plane after image acquisition; and (3) proton density or T2 without fat saturation. The radiologists in our study found that the coronal MRI sequence was the most helpful in visualization of the ALL, that T2 was more helpful in visualizing an ALL injury, and that T1 and T2 were equivalent in identifying an intact ALL.

Given the low agreement between radiologists evaluating the ALL on MRI, ultrasound (US) could serve as an alternative imaging modality. Studies comparing US to anatomic dissection as a gold standard have shown mixed results. Capo et al[2] performed a study on 10 cadaveric knees, attempting to correlate US visualization of the origin and insertion of the ALL with the actual origin and insertion of the ALL identified after dissection. The study found that US and dissection had minimal agreement (intraclass correlation coefficient [ICC] = 0.308) and showed that US was unable to reliably identify the ALL compared with anatomic dissection. Interestingly, interrater reliability of US in the study was high, with an ICC of 0.975.[2] Cavaignac et al[3] performed a similar study in cadaveric knees comparing US and anatomic dissection. The authors found that US had 100% sensitivity in detecting the ALL and that agreement between US and dissection was high, with a Cohen kappa of 0.88 to 0.94.[3] Their study did not measure interrater reliability between multiple radiologists, however. Last, a recent study using US found that there was a high incidence of distal anterolateral complex injuries in ACL-injured knees. Of note, the study showed high interrater reliability for US (ICC = 0.87) between 2 musculoskeletal sonographers.[16] The inconsistency of these results suggests that further study of US as a diagnostic technique for ALL injuries is warranted.

Another consideration in the evaluation of ALL injuries is how to proceed when an injury is diagnosed. The current literature offers no evidence for or against reconstruction of the ALL.

The limitations of our study are that there was no reference standard to determine when nonvisualization of the ALL is secondary to the absence of the ALL, injuries to the ALL, or shortcomings of imaging. The lack of a reference standard also limited the ability to claim whether perceived

ALL injuries were real. Another major limitation to this study is that intrarater agreement was not conducted.

CONCLUSION

Visualization of the ALL was inconsistent in the current study. Identifying and grading an injury to the ALL were difficult and had poor interobserver agreement. Using MRI to aid in the diagnosis of an ALL injury in the setting of an ACL tear is unreliable according to our study results. Further research looking at consistent ALL identification and injury patterns should be undertaken.

ACKNOWLEDGMENT

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