RESEARCH ARTICLE

Associations between MRI Findings of the Anterolateral Ligament in Knee Injuries and Clinical Variables in Candidates for Anterior Cruciate Ligament Reconstruction

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Abstract

Objectives: To evaluate the associations between magnetic resonance imaging (MRI) findings of the anterolateral ligament (ALL) and clinical variables in patients undergoing anterior cruciate ligament (ACL) reconstruction.

Methods: This retrospective multicenter study included patients with clinically confirmed ACL tears scheduled for reconstruction between January and August 2024 at three orthopedic centers in Mashhad. MRI examinations were performed using a 1.5-T scanner and interpreted by two to three experienced radiologists. Associations between MRI-detected ALL injuries and clinical variables were analyzed statistically.

Results: Eighty-three patients (mean age, 29 years; 90.6% male) were included. MRI identified ALL injuries in 34 patients (41.0%), while 45 patients (54.2%) had no detectable ALL injury; four cases were unclassified. oncomitant ACL and ALL injuries were present in 41.7% of patients. A high-grade pivot shift test was positive in 54.2% of cases. Medial and lateral meniscal injuries were observed in 53.0% and 13.3% of patients, respectively, and joint effusion was present in 60.2%. Significant associations were found between ALL injury and MRI-detected effusion (P = 0.035) as well as a positive pivot shift test (P < 0.001). No significant relationships were observed between ALL injury and age, sex, or anterior drawer test findings.

Conclusion: ALL injuries were significantly associated with joint effusion and positive pivot shift test results in patients undergoing ACL reconstruction. Although a possible association with posterior cruciate ligament buckling was observed, larger studies are needed to confirm this finding.

Level of evidence: III

Keywords: Anterior cruciate ligament (ACL), Anterolateral ligament (ALL), Concomitant injury, Magnetic resonance imaging (MRI), Pivot shift test

Introduction

Anterior cruciate ligament (ACL) injuries of the knee represent a significant burden for both athletes and the general population, frequently leading to functional limitations, pain, and an increased risk of osteoarthritis.[1] Magnetic resonance imaging (MRI) is considered the gold standard and the first non-invasive modality for investigating suspected meniscal and ligamentous tears of the knee. In the context of trauma, MRI is generally regarded as a valuable diagnostic tool.[2] While extensive biomechanical and clinical research has focused on the ACL, the anterolateral ligament (ALL), a secondary stabilizer of the knee joint, has historically received less attention. To emphasize the importance of ALL, studies have reported a high frequency of combined ALL and ACL injuries, as well as persistent knee instability following isolated ACL reconstruction (79%).[3] The anterolateral ligament (ALL) originates from the lateral femoral epicondyle, with some of its fibers blending into the

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proximal part of the lateral collateral ligament (LCL).[3] The ALL then follows an anterior oblique course, with firm attachments to the lateral meniscus, and is inserted into the proximal aspect of the anterolateral tibia, well posterior to Gerdy's tubercle.[3,4] However, recent biomechanical studies have elucidated the ALL's critical role in rotational stability, particularly in preventing excessive internal tibial rotation during pivoting and cutting maneuvers.[4] A deficiency in the ALL may lead to persistent rotational instability, even after successful ACL reconstruction, potentially resulting in graft failure or residual functional deficits.[4,5] The ALL can be visualized as a sheet-like structure along the lateral knee, attaching to the distal femur, the body of the lateral meniscus, and the proximal tibia in most MRI scans. It is best assessed using PD-weighted sequences and T2 sequences with fat saturation on the coronal plane [Figure 1].[6] However, in some cases, the ALL cannot be visualized on MRI due to its thin structure and oblique course, as well as the potential presence of partial volume effects. The complexity of diagnosing ALL injuries arises not only from the variability of MRI findings but also from the potential overlap with other knee pathologies. Patients presenting with ACL injuries often exhibit concomitant damage to other knee structures, including meniscal tears and collateral ligament injuries.[7]

Consequently, there has been growing recognition of the importance of evaluating the ALL in patients with ACL injuries. In some cases, concomitant reconstruction of the ALL alongside ACL reconstruction has been advocated.[8] Factors such as age, levels of sport participation—particularly in pivoting sports—specific clinical tests indicative of increased rotational laxity (e.g., a high-grade pivot shift), Segond fractures, and revision ACL reconstruction can influence the decision to address the ALL in addition to ACL reconstruction.[9] Currently, while MRI is used to identify ACL tears, there is limited research on how specific MRI findings related to ALL injuries correlate with clinical parameters and influence subsequent surgical decision-making. Some studies have questioned the role of MRI in detecting combined ACL and ALL injuries.[10] For example, there is a lack of clear criteria regarding the severity or type of ALL injury on MRI that should prompt surgical intervention.

This study aims to evaluate the associations between MRI findings of anterolateral ligament (ALL) injuries and relevant clinical variables in patients undergoing anterior cruciate ligament (ACL) reconstruction. By focusing on ALL injuries, we aim to provide a clearer understanding of how these injuries manifest in imaging studies and how they relate to patient demographics and concomitant knee injuries. Additionally, we will explore correlations with clinical examination results, including functional assessments and subjective reports of instability. The insights gained from this research are intended to enhance diagnostic accuracy and inform treatment decisions for clinicians managing ACL injuries. By elucidating the relationship between MRI findings of ALL injuries and various clinical factors, this study aims to bridge the existing knowledge gap and provide a foundation for future investigations in this critical area of sports medicine. Ultimately, a better understanding of ALL injuries may lead to more tailored rehabilitation strategies, improved surgical outcomes, and an enhanced quality of life for patients recovering from ACL-related knee injuries.

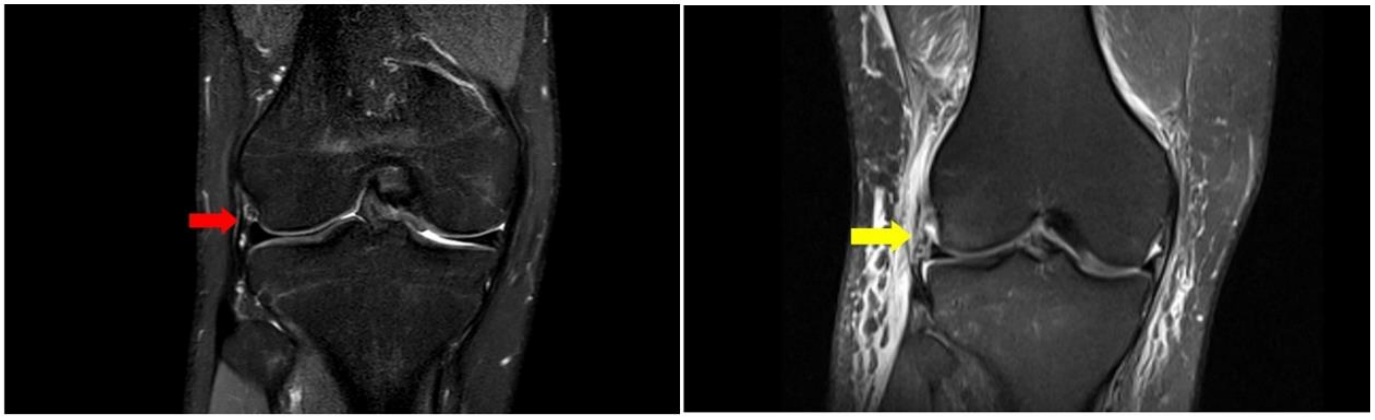

Figure 1. Left image - Coronal PD-weighted fat-saturated image of a patient's right knee, the red arrow indicated an intact ALL; Right image - Coronal PD-weighted fat-saturated image of a patient's right knee; the yellow arrow highlights edema and discontinuity in the ALL PD: Proton Density, ALL: Anterolateral Ligament

Materials and Methods

This multicenter, retrospective study was conducted at three orthopedic surgical centers in Mashhad. The research analyzed data from patients with clinically confirmed anterior cruciate ligament (ACL) tears who were scheduled for ACL reconstruction surgery. Patients were recruited from outpatient orthopedic clinics over six months, from January 2024 to August 2024, and magnetic resonance imaging (MRI) was performed within 30 days of their knee injury.

Inclusion Criteria

Patients included in the study had a primary diagnosis of an acute ACL tear, confirmed through physical examination (positive Lachman test and/or anterior drawer test) and clinical symptoms. Additionally, they had undergone an MRI of the affected knee before the surgical procedure and were aged between 15 and 50 years.

Exclusion Criteria

Patients were excluded from the study if they had undergone any prior surgical intervention on the affected knee, had evidence of pre-existing osteoarthritis in the affected knee as determined by radiographs or MRI, had known ligamentous hyperlaxity conditions, such as Ehlers-Danlos Syndrome or other connective tissue disorders, were diagnosed with inflammatory arthritis (including rheumatoid arthritis or psoriatic arthritis), or had multiple ligament injuries.

Ethical Considerations

This study was approved and supervised by the Ethics Committee of the Research Department at Mashhad University of Medical Sciences (Reference number: IR.MUMS.IRH.REC.1403.019). All patient data were anonymized, and no identifiable health information was shared. Written informed consent was obtained from all patients before their participation, and they were informed of their right to withdraw from the study at any time without any impact on their medical care.

Sampling and Data Collection

A power analysis was conducted based on previous studies investigating the prevalence of anterolateral ligament (ALL) injuries in the context of anterior cruciate ligament (ACL) tears. One prior study indicated a concomitant ALL injury prevalence of approximately 50% among patients with ACL tears. Using a two-sided alpha level of 0.05 and a power of 0.80 (beta of 0.20),[11] the sample size calculation was performed using a power formula, which resulted in a minimum required sample size of 62 patients. This sample size was considered sufficient to detect an association between ALL injuries and the variables of interest. However, 83 patients were evaluated in this study.

Demographic data, including age and sex, as well as clinical and radiological information, were collected for each participant.

1) MRI Reports

The MRI scans were performed with planes aligned both parallel and perpendicular to the long axis of the femur. Two board-certified musculoskeletal radiologists, each with a minimum of five years of experience and unaware of the patients' clinical examination outcomes, interpreted the images. Any discrepancies regarding the presence of an ALL injury were resolved through consensus with a third radiologist. All MRI scans were acquired using a 1.5 Tesla MRI machine, capturing sagittal, coronal, and axial images. The radiologists assessed the presence or absence of ALL injuries, ACL tears, medial and lateral meniscal injuries, periarticular bone contusions, and knee joint effusion. Anterior tibial translation (ATT), which indicates an abnormal relationship between the tibia and femur associated with ACL injury, was considered abnormal if it exceeded 7 mm in this study.[12] A buckled appearance of the posterior cruciate ligament (PCL) on sagittal MR images, resembling a slack PCL and resulting from anterior tibial displacement, was also evaluated.[13] The femoral lateral deep notch sign was assessed, defined as a depth greater than 1.5 mm in the lateral condyle of the femur.[14] This sign indicates an ACL tear and serves as an indication for combined reconstruction surgery of the ACL and anterolateral ligament (ALL). Furthermore, RAMP lesions, which manifest as abnormal signals at the outermost part of the posterior horn of the medial meniscus, were also evaluated.[15] Finally, a bucket handle tear, characterized by midline displacement of the torn meniscus, was investigated.[16]

2) Clinical Findings

Pre-operative physical examinations were conducted by two board-certified orthopedic surgeons who were unaware of the MRI results. Each surgeon independently evaluated every patient, and a third orthopedic surgeon resolved any discrepancies in their findings. The results were documented in the patients' charts. For the assessment of ACL tears, both the Lachman test and the anterior drawer test were performed. The Lachman test was recorded as positive if an anterior tibial translation of 2 mm or more was observed. Similarly, the anterior drawer test results were classified as positive or negative based on whether there was an anterior tibial translation of at least 2 mm.[17] The pivot shift test evaluates anterolateral rotatory instability and helps assess both ACL and ALL injuries. Compared to the previously mentioned tests, the pivot shift test is more sensitive and specific for ALL injuries, making it the most practical examination for ALL, according to orthopedic surgeons.[17] The results of this test were categorized according to the Noyes classification: 0 for negative, 1+ for subtle pivot shift, 2+ for moderate pivot shift, and 3+ for gross pivot shift. For this analysis, pivot shift test outcomes were grouped as negative or low-grade positive (Grade 1+) and high-grade positive (Grade 2+ or 3+).[18]

Statistical Analysis

Data were coded and imported into SPSS version 27. Descriptive statistics were used to summarize demographic information, MRI findings, and clinical variables. Categorical variables were presented as frequencies and percentages, while continuous variables were expressed as means ± standard deviations. The associations between MRI-detected anterolateral ligament (ALL) injury and other categorical variables, particularly the positive pivot shift test, meniscal tears, and anterior cruciate ligament (ACL) tears, were analyzed using Chi-square tests or Fisher's exact tests, as appropriate. Statistical significance was set at a P-value < 0.05 for all tests.

Results

Eighty-three patients diagnosed with an anterior cruciate ligament (ACL) tear and scheduled for ACL reconstruction surgery were included in this study, with a mean age of 29 years (SD = 7.98, range 15–49). The cohort had a predominance of males, comprising 90.6% of the

participants [Table 1]. MRI results revealed that 34 patients (41%) had associated anterolateral ligament (ALL) injuries, while 45 patients (54.2%) showed no injuries, and ALL was not detectable in four cases (4.8%). Nearly all patients exhibited a positive anterior drawer test (98.8%), and the pivot shift test was positive in 45 patients (54.2%). ACL injury was present on MRI in 81 patients (97.6%). Furthermore, medial meniscus injuries and lateral meniscus injuries were observed in 53% and 13.3% of patients, respectively. As shown in [Table 1], joint effusion was present in 50 patients (60.2%), and the femoral lateral deep notch sign was positive in 5 patients (6%). One patient was diagnosed with a Segond fracture. The mean anterior tibial translation (ATT) measurement was 9.8 mm (SD = 2.9, range 7–18 mm).

Table 1. Frequency of findings in demographics, physical examinations, and MRI Reports

Variables		Number (%)	Specific MRI Findings		Number (%)
Sex	*Male*	75 (90.6)	Injury of medial meniscus	With injury	44 (53)
	Female	8 (9.6)		Without injury	39 (47)
Anterior drawer test	*Positive*	82 (98.8)	Injury of lateral meniscus	With injury	11 (13.3)
	Negative	1 (1.2)		Without injury	72 (86.7)
Lachman test	*Positive*	78 (94)	Effusion	Positive	50 (60.2)
	Negative	5 (6)		Negative	33 (39.8)
Pivot shift test	*2+ or 3+*	45 (54.2)	Contusion	Positive	37 (44.6)
	Negative or 1+ positive	38 (45.8)		Negative	46 (55.4)
ALL injury (on MRI)	*With injury*	34 (41)	RAMP lesion	Positive	24 (28.9)
	Without injury	45 (54.2)		Negative	59 (71.1)
	Non-diagnostic	4 (4.8)		-	-
ACL Injury (on MRI)	*With injury*	81 (97.6)	Bucket handle tear	Positive	19 (22.9)
	Without injury	2 (2.4)		Negative	64 (77.1)
Age	*> 20 years*	66 (79.5)	ATT	Positive	37 (46.4)
	< 20 years	17 (20.5)		Negative	46 (55.4)
PCL buckling	*Positive*	49 (59)	Femoral lateral deep notch sign	Positive	5 (6)
	Negative	34 (41)		Negative	78 (94)

MRI: Magnetic Resonance Imaging, ALL: Anterolateral Ligament, ACL: Anterior Cruciate Ligament, ATT: Anterior Tibial Translation, PCL: Posterior Cruciate Ligament

The association between demographic factors, clinical examinations, and MRI findings in 79 patients with confirmed anterolateral ligament (ALL) injury based on MRI is summarized in [Table 2]. Regarding MRI findings, 41.7% of patients (33 out of 79) exhibited both confirmed anterior cruciate ligament (ACL) and ALL injuries. There were no significant differences in age or sex between patients with and without MRI-detected injuries. However, a significant association was identified between joint effusion and ALL injury (P-value = 0.035). The pivot shift test demonstrated strong statistical significance, with a P-value of < 0.001, indicating that a positive result on this test was significantly associated with an increased likelihood of ALL injury. Although not statistically significant (P-value = 0.053), a trend was observed between ALL injury and posterior cruciate ligament (PCL) buckling. Furthermore, no statistically significant associations were found between ALL injury and other variables.

Discussion

This study investigated the relationship between MRI findings of anterolateral ligament (ALL) injuries and various clinical factors in patients undergoing anterior cruciate ligament (ACL) reconstruction. Our findings reveal a significant prevalence of ALL injuries (41.7%) in this population, emphasizing the importance of considering these concomitant injuries in the assessment and management of ACL-deficient knees. A key observation is the strong association between a positive pivot shift test and MRI-detected ALL injury. However, assessing the ALL via MRI can be challenging and contentious due to its thin structure, orientation, and proximity to surrounding anatomical features.[11] Visualizing all three segments of the anterolateral ligament (ALL)—proximal, middle, and distal—remains particularly challenging, with only 11% of cases successfully identifying these components.[19] Furthermore, accurately identifying and grading ALL injuries has been problematic.[19] In this study, the MRI features of the ALL were observed in the majority of patients, with invisibility limited to only four individuals, resulting in a visualization rate of 95.2%. Other

studies have reported varying success rates, ranging from complete visualization in all patients to only 50%.[20] The ability to detect ALL may be influenced by the radiologist's experience and skill, as well as the strength of the MRI machine used; for instance, 3.0-T MRI systems have demonstrated greater accuracy in identifying ALL compared to 1.5-T systems.[20] Our study employed a 1.5-T MRI; however, previous research indicates that this method can successfully visualize at least a portion of the anterolateral ligament (ALL) in 97.8% of cases.[6]

Table 2. Association of ALL injury with other findings

Variables			Intact ALL in MRI N (%)	Injured ALL in MRI N (%)	P-value
Demographic	Age	*> 20 years*	35 (55.6)	28 (44.4)	0.616
		< 20 years	10 (62.5)	6 (37.5)	
	Sex	*Male*	40 (55.6)	32 (44.4)	0.418
		Female	5 (71.4)	2 (28.6)	
MRI Findings	*ACL injury*	Intact	1 (50)	1(50)	0.84
		Injured	44 (57.1)	33(42.9)	
	Medical meniscus	Intact	21(56.8)	16 (43.2)	0.972
		Injured	24 (57.1)	18 (42.9)	
	Lateral meniscus	Intact	40 (58)	29 (42)	0.634
		Injured	5 (50)	5 (50)	
	Bucket handle tear	Negative	36 (60)	24 (40)	0.332
		Positive	9 (47.4)	10 (52.6)	
	Effusion	Negative	21(72.4)	8 (27.6)	0.035
		Positive	24(48)	26 (52)	
	Contusion	Negative	26 (61.9)	16 (38.1)	0.344
		Positive	19 (51.4)	18 (48.6)	
	RAMP	Negative	31(54.4)	26 (45.6)	0.457
		Positive	14 (63.6)	8 (36.4)	
	PCL buckling	Negative	23 (69.7)	10 (30.3)	0.053
		Positive	22 (47.8)	24 (52.2)	
	Femoral lateral deep notch sign	Negative	44 (59.5)	30 (40.5)	0.085
		Positive	1(20)	4 (80)	
	ATT	Negative	25 (55.6)	20 (44.4)	0.771
		Positive	20 (58.8)	14 (41.2)	
Clinical Examination	Pivot shift test	Negative or 1+	29 (80.5)	7 (19.5)	< 0.001
		2+ or 3+	16 (37.2)	27 (62.8)	

ALL: Anterolateral Ligament, MRI: Magnetic Resonance Imaging, ACL: Anterior Cruciate Ligament, PCL: Posterior Cruciate Ligament, ATT: Anterior Tibial Translation

In our evaluation, we found that 33 patients (41.7%) had both MRI-confirmed anterior cruciate ligament (ACL) and anterolateral ligament (ALL) injuries. This rate differs from findings in similar studies; for instance, concomitant ACL and ALL injuries were noted in 17% of cases,[20] while ALL tears were found in 29.3% of 48 patients in another study.[21] Among 30 individuals suspected of ACL injuries, MRI revealed ALL injuries in 53% of cases.[7] In another related study, a significant portion (78.8%) of 206 patients with ACL injuries had concurrent ALL injuries, primarily affecting the distal segment.[8] A deep lateral femoral notch larger than 1.8 mm has been identified as an indicator of combined ACL and ALL injury.[20] Interestingly, Monaco et al. found that a notable percentage (84.6%) of ALL/lateral capsule injuries on MRI were associated with ACL involvement.[22] While these findings suggest that MRI is functional for diagnosing combined ACL and ALL injuries, other research, such as that by Marshall et al., has shown MRI to be less effective in detecting concomitant injuries.[19] Consequently, it is essential to resolve this controversy, as ALL injury on MRI may indicate the need for surgical reconstruction of both the ACL and ALL. For instance, the presence of a lateral femoral notch sign on preoperative imaging and a Segond fracture are both radiological indications for ALL reconstruction among patients with ACL injuries.[9]

A high-grade pivot shift test is a significant surgical indicator

for simultaneous surgery on anterior cruciate ligament (ACL) and anterolateral ligament (ALL) injuries. Our findings suggest that identifying an ALL injury through MRI could enhance preoperative assessments and is significantly associated with high-grade pivot shift tests. Similarly, Song et al. found that the prevalence of MRI-confirmed ALL injuries was notably higher among patients exhibiting high-grade (+3 and +2) pivot shifts (94.1%) compared to those with lower grades (64.6%), indicating a strong correlation between severe pivot shifts and concomitant ALL injuries in patients with acute ACL injuries. This association was even more pronounced in patients with a pivot shift grade of +3 compared to those with a grade of +2 (94.1% vs. 64.6%). In contrast to our findings, research with a similar sample size indicated that MRI evaluations of the anterolateral capsule did not significantly affect pivot shift results in ACL-injured knees across 84 patients.[18] Therefore, further studies with larger sample sizes are necessary to clarify the association between this clinical test and MRI-confirmed ALL injuries.

Furthermore, we observed a significant association between the presence of knee effusion on MRI and anterolateral ligament (ALL) injury. While effusion is a common finding in anterior cruciate ligament (ACL) injuries, its association with ALL injury suggests that this combined injury pattern may lead to increased intra-articular inflammation. This finding could potentially alert orthopedic surgeons to the risk of underdiagnosing injured ALL in patients with diagnosed ACL injuries. Regarding periarticular bone contusions, no significant association was found in the current study. However, this contrasts with some studies that have reported a correlation between concomitant ALL and ACL injuries and periarticular bone edema.[7] In our study, RAMP lesions were identified in 28.9% of patients; however, we did not find a significant association between RAMP lesions and ALL injuries. Despite this, Stranger et al. found a significant association between ALL injuries and RAMP lesions in their evaluation of 164 patients with ACL injuries, identifying 28 patients with both conditions.[21]

The study revealed a trend suggesting a possible relationship between anterolateral ligament (ALL) injuries and posterior cruciate ligament (PCL) buckling (P-value = 0.053), although this did not reach statistical significance. Furthermore, no significant association was detected between both meniscus and ALL injury. Conversely, similar research has found that injury to the posterior horn of the lateral meniscus is associated with ALL injury in patients with anterior cruciate ligament (ACL) injuries.[21] Therefore, the potential clinical significance of this trend should not be overlooked. Patients presenting with complex meniscal and ACL injuries should be thoroughly evaluated for possible ALL injuries.

We identified only one case of a Segond fracture; however, investigations conducted on cadaveric knees have suggested that this type of bone avulsion is significantly associated with anterolateral ligament (ALL) injuries.[23] It is important to note that the study did not find any statistically significant relationships between ALL injuries and other factors, including age, sex, and anterior tibial translation (ATT) measurements. Consistent with our results, Dimitriou et al. did not observe any differences between genders or age groups concerning concomitant ALL and anterior cruciate ligament (ACL) injuries.[20]

Several limitations must be considered when interpreting the results of this study. For variables with lower prevalence, such as lateral meniscus tears or Segond fractures, larger studies are needed to confirm or refute the trends observed in this study. First, MRIs were performed at different imaging centers, each using varying protocols and quality standards. Second, the study population comprised patients already scheduled for anterior cruciate ligament (ACL) reconstruction, which may introduce selection bias. As a result, the findings may not be generalizable to all patients with ACL injuries, particularly those managed non-operatively. Third, since this is a retrospective study, MR scans were not performed within the same time frame after knee injury for all patients (ranging from days to a month), which may have influenced the presence of bone contusions and joint effusions.

Conclusion

This study provides valuable insights into the relationship between MRI findings of anterolateral ligament (ALL) injuries and clinical parameters in patients undergoing anterior cruciate ligament (ACL) reconstruction. The significant associations between ALL injury and a positive pivot shift test, as well as knee effusion observed on MRI, highlight the importance of both clinical and imaging assessments of the ALL in ACL-injured patients. This study demonstrates that while imaging, particularly MRIs, may not fully replace clinical examinations for evaluating ALL injuries, it can assist surgeons in making informed decisions in ambiguous cases. The implications of our findings extend beyond diagnostic accuracy; they also inform treatment decisions and rehabilitation strategies. A more precise understanding of the relationship between ALL injuries and ACL tears can guide clinicians in developing tailored rehabilitation protocols that address both ligamentous and meniscal injuries concurrently. Furthermore, enhanced diagnostic accuracy may lead to improved surgical outcomes by ensuring that all relevant injuries are addressed during ACL reconstruction. Future studies should focus on larger, prospective cohorts, incorporate arthroscopic confirmation of ALL injuries, and investigate the impact of ALL-specific interventions on patient outcomes. The long-term goal is to improve diagnostic accuracy, inform treatment decisions, and ultimately enhance the quality of life for patients recovering from ACL-related knee injuries.

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