The anterolateral capsule is infrequently damaged as evaluated arthroscopically in patients undergoing anatomic ACL reconstruction

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ABSTRACT

Objectives: Concomitant anterolateral complex (ALC) injury may contribute to persistent rotatory knee instability following anterior cruciate ligament (ACL) reconstruction. There is no consensus on how to best identify concomitant ALC injury preoperatively, nor how well ALC injury identified on imaging modalities correlates with clinical examination of knee instability.

The purpose of this retrospective study was to determine the incidence of concomitant ALC injury in ACL-injured knees, as determined by arthroscopy to preoperative radiography, ultrasound, and MRI.

Methods: A total of 117 patients with a unilateral primary ACL injury who underwent individualized anatomic ACLR between June 2016 and May 2019 were enrolled. Preoperative imaging modalities, including X-ray, ultrasound, and MRI, were evaluated for concomitant ALC injury. Clinical examination under anesthesia, including the anterior drawer, Lachman, and pivot shift tests were performed. Anterolateral capsule injury, as defined by hemorrhage and/or capsular tearing on diagnostic arthroscopy, was also determined. Correlative analyses of ALC injury incidence and severity were performed across imaging modalities and against clinical examination grades.

Results: ALC injury incidence across imaging modalities was as follows: X-ray (3%), arthroscopy (19%), MRI (53%), and US (63%). The ALC injury rate on arthroscopy was significantly less than MRI ($p < 0.001$) or ultrasound ($p < 0.001$). ALC injury incidence and severity were significantly correlated between MRI and US grading scales ($p = 0.02$), but no correlations among other imaging modalities were found. Similarly, no imaging modality meaningfully correlated with physical examination maneuvers.

Conclusion: The incidence of ALC injury varies across imaging modalities, with lower injury rates found on arthroscopy (19%) compared to MRI (53%) and US (63%). Increasing ALC injury severity grades on imaging does not predict increasing anterolateral knee laxity on clinical examination.

Level of evidence: V, retrospective case series.
What are the new findings?

- This study introduces a new scale for grading anterolateral capsule injury by arthroscopy.
- Anterolateral capsule injury was seen less frequently by arthroscopy (19%) as compared to MRI (53%) and ultrasound (63%).
- Increasing anterolateral capsule injury severity, as determined by injury scales across different imaging modalities, did not correlate with anterolateral knee laxity on clinical examination.
- Preoperative imaging presently has limited value in determining indications for lateral augmentation procedures during concomitant ACL reconstruction.

Introduction

The anterolateral complex (ALC) of the knee, which is comprised of several structures including the anterolateral capsule and its variable thickening, most recently referred to as the anterolateral ligament (ALL), is a secondary stabilizer to the anterior cruciate ligament (ACL) in controlling anterolateral rotary stability of the knee [1]. Surgical augmentation of the ALC combined with anatomic ACLR has been reported to improve anterolateral rotary knee stability and reduce graft failure as compared to anatomic ACLR alone at short-term follow-up in a young and active patient population [2–5], but the long-term outcomes and indications for ACL augmentation remain unclear [1]. Limiting efforts to define surgical indications for ACL augmentation is the variability in the reported incidence of concomitant ACL injury [6]. In ACL-injured knees, concomitant ACL injury has been reported at rates of 11–79% on MRI [7,8] and 33–63% on ultrasound [9,10]. The highest rates of ACL injury have been reported with open surgical inspection of the anterolateral capsule at the time of ACLR, with capsular hemorrhage reported in >90% of cases [11,12]. On the other hand, open ACL exploration may impart undue morbidity to otherwise arthroscopic surgery, especially absent clear indications for operative augmentation of the ALC.

Given the thin, often translucent, structure of the anterolateral capsule of the knee, injury indicated by hemorrhage may be visualized in the capsule during diagnostic arthroscopy, thereby reducing the morbidity of open surgical exploration while potentially providing the most sensitive imaging modality to assess ACL injury concomitant with ACL rupture. The purpose of this retrospective study was to determine the incidence of concomitant anterolateral capsule injury in ACL-injured knees, as determined by diagnostic arthroscopy to preoperative radiography, ultrasound, and MRI. It was hypothesized that the incidence of concomitant anterolateral capsule injury would be highest with arthroscopic evaluation.

Methods

The study was approved by the institutional review board (STUDY1903019) at the University of Pittsburgh. This study was a retrospective case series of patients with a unilateral primary ACL injury who underwent individualized anatomic ACLR between June 2016 and May 2019. Inclusion criteria were patients aged 13 and 65 years old with an ACL injury scheduled to undergo individualized anatomic ACLR by the senior author. Patients were excluded if they had a multiligament injury necessitating concomitant repair or reconstruction (e.g., MCL reconstruction), complete meniscal insufficiency, or chondral injury necessitating osteochondral allografting or autografting. Overall, 117 patients were included in the study. Patient characteristics are summarized in Table 1.

As a standard practice of the senior author, patients underwent preoperative evaluation, including clinical examination (i.e., anterior drawer, Lachman, pivot shift), radiographs, ultrasound of the ACL, and MRI of the knee.

Standard plain films of the knee were read by a fellowship-trained musculoskeletal radiologist not otherwise involved in the project. The radiologist that evaluated radiographs was not the same radiologist who evaluated MRI and was blinded to the findings of the clinical examination, ultrasound, and MRI. Plain films were noted for the presence or absence of a Segond fracture.

All ultrasound examinations were performed by a fellowship-trained physiatrist with more than eight years of training in musculoskeletal ultrasound, using an 18–4 MHz linear-array transducer (Samsung Medicine RS80 Prestige, Samsung Medicine, Seoul, South Korea), according to a previously published protocol [10]. The physiatrist was blinded to the findings of the clinical examination, radiography, and MRI. Evaluations of the ALC by ultrasound were classified based on the relative echogenicity at its tibial insertion and on the presence of a Segond fracture as follows: Grade 0: isoechoic to the rest of the ALC; Grade 1: hypoechoic; Grade 2: anechoic; and Grade 3: Segond fracture (Fig. 1) [10].

MRI was performed using a 1.5-T open-bore magnet with a 3-mm slice thickness (Signa; GE Healthcare) and with the patient supine and the knee near full extension. MRI scans were independently reviewed by one fellowship-trained musculoskeletal radiologist, who was blinded to the results of the clinical examination, radiography, and ultrasound. MRI evaluation of the ALC was graded according to a previously established scale as follows: Grade 0: normal; Grade 1: minimal intrinsic and/or adjacent edema; Grade 2: edema within the anterolateral capsule with a partial disruption of fibers; Grade 3: complete disruption of anterolateral capsular fibers and/or Segond fracture (Fig. 2) [13,14].

Arthroscopic, intraarticular photographs of the anterolateral capsule were taken intraoperatively by the senior author and independently evaluated by two orthopedic surgeons otherwise blinded to the intraoperative findings documented by the senior author. The arthroscopic, intraarticular photographs of the anterolateral capsule were graded as follows: Grade 0: no hemorrhage, no lesion of the capsule; Grade 1: local hemorrhage, no frank capsular tear; Grade 2: hemorrhage and frank capsular tear (Fig. 3).

Clinical examination, including the anterior drawer test, Lachman test, and pivot shift tests, was independently performed by two orthopedic surgeons blinded to the findings on radiography, ultrasound, and MRI. Clinical examination maneuvers were graded according to the International Knee Documentation Committee (IKDC) form. Anterior drawer and Lachman test grades included 0 (–1 to 2 mm), 1 (3–5 mm), 2 (6–10 mm), and 3 (>10 mm). Pivot shift grades included 0 (normal), 1 (glide), 2+ (chunk), and 3+ (gross). Where there was disagreement on the subjective score of a clinical examination test, the surgeons discussed at the time of performance and arrived at a consensus. Arbitration by a third party was not required.

Data were analyzed using Prism 8 statistical software (GraphPad, San Diego, CA, USA). Descriptive statistics are reported as means ± standard error.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Patient and surgical characteristics.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years, mean ± SD (range)</td>
<td>26.2 ± 12.2 (13–65)</td>
</tr>
<tr>
<td>Male gender, n (%)</td>
<td>65 (56%)</td>
</tr>
<tr>
<td>Days from injury to surgery, mean ± SD (range)</td>
<td>351 ± 1940 (8–19463)</td>
</tr>
<tr>
<td>Days from injury to surgery, median (Inter Quartile Range)</td>
<td>49 (IQR 89.3)</td>
</tr>
<tr>
<td>Laterality, right, n (%)</td>
<td>62 (53%)</td>
</tr>
<tr>
<td>Surgery type, n (%)</td>
<td></td>
</tr>
<tr>
<td>• Single bundle</td>
<td>93 (80%)</td>
</tr>
<tr>
<td>• Single bundle with remnant preservation</td>
<td>5 (4%)</td>
</tr>
<tr>
<td>• Double bundle</td>
<td>7 (6%)</td>
</tr>
<tr>
<td>• One bundle (PL) augmentation</td>
<td>12 (10%)</td>
</tr>
<tr>
<td>Graft Type, n (%)</td>
<td></td>
</tr>
<tr>
<td>• BTB autograft</td>
<td>6 (5%)</td>
</tr>
<tr>
<td>• HT autograft</td>
<td>59 (51%)</td>
</tr>
<tr>
<td>• QT autograft</td>
<td>26 (22%)</td>
</tr>
<tr>
<td>• Allograft</td>
<td>26 (22%)</td>
</tr>
<tr>
<td>Graft diameter in SB, mm, mean ± SD (range)</td>
<td>8.8 ± 1.0 (7–11)</td>
</tr>
<tr>
<td>Meniscus status, intact, n (%)</td>
<td>61 (52%)</td>
</tr>
<tr>
<td>Cartilage status, intact, n (%)</td>
<td>98 (84%)</td>
</tr>
</tbody>
</table>

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coefficients were also determined, assuming non-parametric distribution of data, but are not reported as they did not differ from results according to Pearson’s correlation coefficients. Anterolateral capsular injury, as constituted by any abnormality on imaging, was also dichotomized (i.e., yes/no), and a Fisher’s exact test was performed to determine statistically significant differences in injury incidence among imaging modalities. Using the dichotomized injury incidence as the primary outcome, a post-hoc power calculation was performed. As spontaneous healing of anterolateral capsule injuries has been reported [15,16], subgroup analyses of injury incidence and severity according to time from injury to surgery (<6 weeks, 6–12 weeks, >12 weeks) were performed using chi-squared tests. For all analyses, statistical significance was defined as α = 0.05.

Results

A total of 117 patients were included in the study, with demographic information and surgical characteristics included in Table 1. A Segond fracture was found on plain films in 3 of 117 cases (3%). Image modalities, including ultrasound, MRI, and arthroscopy, were graded according to the scales described above, with results summarized in Table 2.

When ALC injury was dichotomized (i.e., yes/no) for each imaging modality, the injury incidence was as follows: ultrasound (63%), MRI (53%), and arthroscopy (19%), constituting a significant difference between ultrasound (US) and arthroscopy (P < 0.001) and MRI and arthroscopy (P < 0.001) but not US and MRI (P = 0.17). Similarly, using the ordinal grading scales, ultrasound and MRI scores were significantly correlated (r = .24; .04 to .41, 95% CI; P = 0.02). There was no significant correlation between ultrasound and arthroscopy scores (r = .03; -.16 to .22, 95% CI; P = 0.75) nor between MRI and arthroscopy scores (r = -.01; -.21 to .18, 95% CI; P = 0.88). Clinical examination grades for the Lachman, anterior drawer, and pivot shift tests were available for 114 patients, with no patient having missing data points for more than one test. The grading of physical examinations is summarized in Table 3.

ALC grades by imaging modalities (i.e., ultrasound, MRI, and arthroscopy) were comprehensively compared against grades of clinical examination maneuvers (i.e., Lachman, anterior drawer, and pivot shift test). There were no significant correlations of ultrasound grades with Lachman test grades (r = -.05; -.24 to .14, 95% CI; P = 0.59) or anterior drawer test grades (r = -.19; -.36 to .01, 95% CI; P = 0.06); however, ultrasound grades were negatively correlated with pivot shift test grades (r = -.22; -.40 to -.03, 95% CI; P = 0.02). There were no significant correlations between MRI grades and Lachman grades (r = .01; -.17 to .19, 95% CI; P = 0.91), anterior drawer grades (r = -.09; -.27 to .10, 95% CI; P = 0.36), or pivot shift grades (r = -.04; -.22 to .15, 95% CI; P = 0.70). There were no significant correlations between arthroscopy grades and Lachman grades (r = -.15; -.33 to .04, 95% CI; P = 0.12), anterior drawer grades (r = .06; -.13 to .25, 95% CI; P = 0.51), or pivot shift grades (r = .14; -.05 to .32, 95% CI; P = 0.16).

Subgroup analyses according to time from injury to surgery (i.e., <6 weeks, 6–12 weeks, >12 weeks) did not reveal any significant effect of time on anterolateral capsule injury incidence or severity across any imaging modality. The distribution of injury grades according to each imaging modality, as delineated across the three time periods, is shown in Supplemental Fig. 1.

Post-hoc power calculations using dichotomized anterolateral capsule injury incidence across imaging modalities as the primary outcome found that observed differences yielded power >90% comparing US vs. arthroscopy and MRI vs. arthroscopy, but only power 34% comparing US vs. MRI. A sample size of 381 patients would be required for power >80% in comparing US vs. MRI given the observed injury incidence.

Discussion

The most important findings of this retrospective case series of 117 ACL-injured knees were as follows: (1) ALC injury, visualized as hemorrhage of the anterolateral capsule during diagnostic arthroscopy, was
observed in 19% of ACL-injured knees, an injury incidence significantly less than that observed on MRI (53%) or ultrasound (63%); (2) ALC injury incidence and severity did not significantly differ between MRI and US grading scales; (3) No ALC injury grading scale on any imaging modality meaningfully correlated with physical examination maneuvers for anterolateral knee stability, including Lachman, anterior drawer, and pivot shift tests.

While there is no validated scale of ALC injury using any imaging modality, MRI has been the most commonly utilized modality for assessing potential ALC injury, especially in the context of concurrent ACL injury [11,17–19]. A four-point grading scale, as previously published [13] with grades of 0 (normal) to 3 (complete disruption of ALC fibers and/or Segond fracture), was employed herein and closely parallels other reported MRI grading scales for ALC injury [7,18]. Accordingly, increased MRI signal constituting an ALC abnormality was observed in 53% of cases, consistent with rates of 11–79% reported in a recent systematic review of MRI studies assessing ALC integrity [7]. In this case series, there were three cases (3%) categorized as grade 3, including two Segond fractures (2%), falling within the reported prevalence of Segond fractures (1–29%) seen on MRI of ACL-injured knees [20–22]. By comparison, seven cases (7%) of Segond fractures were detected using US, consistent with recent studies suggesting that US may be a more sensitive imaging modality for assessing ALC injury, including Segond fractures [9,23].

Fig. 2. MRI grading scale of ALC injury. As the ITB and its capsulo-osseous layer traverse the knee at an oblique angle relative to the knee at full extension, several coronal cuts were examined to fully assess ALC integrity. Representative cuts from a single slice for each grade are shown above. Axial cuts were also examined (not shown). (A) Grade 0, (B) Grade 1, (C) Grade 2, and (D) Grade 3.

Fig. 3. Arthroscopic grading of ALC injury. (A) Grade 0, (B) Grade 1, and (C) Grade 2.

However, this prevalence of ALC abnormality detected by ultrasound in this case series is higher than the rate of 32% found in a smaller case series [10]. Notably, grades according to MRI and ultrasound were significantly correlated. This finding could be anticipated from the similar criteria comprising the respective grading scales of the US and MRI modalities but has not been previously reported.

In contrast to US and MRI, arthroscopic evaluation of the intra-articular ALC using a novel grading scale revealed a lower injury rate, at 19% of cases. The lower injury incidence by arthroscopic evaluation contradicted our hypothesis. The three-point arthroscopic grading scale, including (0) normal, (1) local hemorrhage, and (2) hemorrhage with frank capsular tearing, was adapted from Ferretti et al. [11] who developed a four-point classification system of increasing ALC injury severity based on open surgical exploration of the lateral extraarticular knee. The Ferretti classification does not include a grade for normal (i.e., Type 0). Types 1 and 2 of the Ferretti scale, entailing multilevel rupture with macroscopic hemorrhage of increasing areas of the anterolateral capsule, were combined into a single grade (1) in our arthroscopic scale. Ferretti Type 3, with complete transverse tearing of the anterolateral capsule involving the area of the putative ALL, corresponds to arthroscopic grade 2. Lastly, Ferretti Type 4 constitutes a Segond fracture, which was omitted from the arthroscopic grading scale as the bony avulsion could not be visualized intraarticularly.

The ALC injury incidence of 19% found by arthroscopic evaluation in this study stands in contrast to the >90% injury rate reported with open anterolateral knee exploration [12,24]. While the cause for this discrepancy is unknown, there are several potential explanations. The median time from injury to surgery in the patient cohort of the present...
study was 49 days, while all patients in studies that underwent open anterolateral knee dissection with concurrent ACLR underwent surgery <10 days from the time of injury [12,24]. Hemorrhage associated with acute trauma may have resolved with increasing time from injury, as ACL injuries in the ACL-injured knee have been reported to heal spontaneously, albeit at variable rates [15,22]. Likewise, the diagnosis of concomitant ACL injury on MRI has been reported to decrease with time from injury [25]. However, subgroup analyses in this study did not find a significant difference in ACL injury incidence or severity, as evaluated by any imaging grading scale, with increasing time from injury to surgery (Supplemental Fig. 1). Nevertheless, the open exploration of the anterolateral knee may identify additional injuries (with associated hemorrhage) such as the Segond fracture and/or ITB injury not as easily identified with intraarticular arthroscopy alone. On the other hand, and similar to studies on open anterolateral knee exploration [11,12], this study found no significant correlation between arthroscopic grades and MRI or US grades. It was previously reported [11] that the Ferretti grade derived from open exploration could not be reliably established from MRI and that there was an only fair agreement between MRI and surgical findings regarding ITB abnormalities and whether ALL/anterolateral capsular tears were partial or complete. Therefore, even if ACL injury is grossly identified on various imaging modalities, the ability to grade the severity of ACL injury appears limited, with a poor correlation of ordinal grading scales across imaging modalities. Similarly, no imaging modality was found to meaningfully correlate with clinical examination maneuvers, including Lachman, anterior drawer, and pivot shift tests, performed under anesthesia prior to ACLR. US negatively correlated with grades on the pivot shift tests but is likely an artifact finding secondary to the high distribution of cases with grade 2+ pivot shift within ultrasound grades 0 and 1. The association of increased anterolateral knee laxity with ACL injury found on imaging is inconsistently reported in the literature, with some studies finding a positive association [8,26] while others finding no association [27,28]. These equivocal findings, like much of the controversy regarding the structure and function of the ALC, can be attributed at least in part to heterogeneity in imaging parameters and grading scales, the subjective nature of clinical examination maneuvers (i.e., pivot shift test), differing inclusion and exclusion criteria of patient populations, and the complex interplay of multiple structures comprising the ALC [1,29]. While this study is one of the largest case series investigating the correlations of multiple imaging modalities used to assess preoperative ACL injury concomitant with ACL rupture, it has several limitations. First, the included patient population was not limited to exclusively young and/or “high-risk” patients, as performed in some recent prospective clinical trials [2]. As a result, only 64% of patients had a pivot shift grade ≥2+, and not all patients engaged in high-risk sport activities, limiting the applicability of the study findings to other high-risk patient populations. Likewise, there was no limitation on the time from injury to imaging, which may have underestimated the prevalence of ALC abnormalities detected on imaging if performed closer to the time of injury, as discussed above. Finally, no postoperative outcome measures were included in this study, from which the prognostic value of the preoperative imaging results could be determined.

Table 2

<table>
<thead>
<tr>
<th>Ultrasound</th>
<th>MRI</th>
<th>Arthroscope</th>
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<tr>
<td>0</td>
<td>41%</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>51%</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>11%</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>7%</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>110</td>
<td>Total 111</td>
</tr>
</tbody>
</table>

* Two Segond fractures diagnosed with ultrasound appeared chronic, with five acute Segond fractures.

Table 3

<table>
<thead>
<tr>
<th></th>
<th>Lachman</th>
<th>Anterior drawer</th>
<th>Pivot shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 (0%)</td>
<td>1 to 2 mm</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>1+</td>
<td>10 (9%)</td>
<td>3 to 5 mm</td>
<td>25 (31%)</td>
</tr>
<tr>
<td>2+</td>
<td>103 (90%)</td>
<td>6 to 10 mm</td>
<td>50 (44%)</td>
</tr>
<tr>
<td>3+</td>
<td>1 (1%)</td>
<td>&gt;10 mm</td>
<td>29 (25%)</td>
</tr>
<tr>
<td>Total</td>
<td>114</td>
<td>Total 114</td>
<td>Total 114</td>
</tr>
</tbody>
</table>

Conclusion

This retrospective case series of 117 ACL-injured knees undergoing anatomic ACLR found an ACL injury rate of 19% on diagnostic arthroscopy, significantly less than injury incidence observed on MRI (53%) or ultrasound (63%) and dramatically less than an injury rate of >90% reported in similar studies involving the open exploration of the anterolateral knee. No imaging modality meaningfully correlated with physical examination maneuvers for anterolateral knee stability, including Lachman, anterior drawer, and pivot shift tests. Based on the findings from this study (i.e., low incidence of ACL injury and no correlation of ACL injury to high-grade rotatory knee instability), we do not routinely perform an anterolateral procedure such as lateral extraarticular tenodesis (LET) in patients.

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Author contributions

- TR and BBR made substantial contributions to conception and design, acquisition of data, analysis and interpretation of data, drafted the manuscript, gave final approval of the version to be published, agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
- KO, ACC, DdS made substantial contributions to interpretation of data, gave final approval of the version to be published, agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
- VM and FHJ have made substantial contributions to conception and design, have been involved in revising it critically for important intellectual content, have given final approval of the version to be published, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:
- Volker Musahl reports a relationship with Smith and Nephew Inc that includes consulting or advisory and funding grants.
- Volker Musahl reports a relationship with Arthrex Inc that includes funding grants.
- Freddie Fu reports a relationship with American Journal of Sports Medicine that includes board membership.
- Freddie Fu reports a relationship with DePuy Mitek Inc that includes funding grants.
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Appendix A. Supplementary data

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References


