Anterolateral Knee Extra-articular Stabilizers

A Robotic Sectioning Study of the Anterolateral Ligament and Distal Iliotibial Band Kaplan Fibers

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Background: The individual kinematic roles of the anterolateral ligament (ALL) and the distal iliotibial band Kaplan fibers in the setting of anterior cruciate ligament (ACL) deficiency require further clarification. This will improve understanding of their potential contribution to residual anterolateral rotational laxity after ACL reconstruction and may influence selection of an anterolateral extra-articular reconstruction technique, which is currently a matter of debate.

Hypothesis/Purpose: To compare the role of the ALL and the Kaplan fibers in stabilizing the knee against tibial internal rotation, anterior tibial translation, and the pivot shift in ACL-deficient knees. We hypothesized that the Kaplan fibers would provide greater tibial internal rotation restraint than the ALL in ACL-deficient knees and that both structures would provide restraint against internal rotation during a simulated pivot-shift test.

Study Design: Controlled laboratory study.

Methods: Ten paired fresh-frozen cadaveric knees (n = 20) were used to investigate the effect of sectioning the ALL and the Kaplan fibers in ACL-deficient knees with a 6 degrees of freedom robotic testing system. After ACL sectioning, sectioning was randomly performed for the ALL and the Kaplan fibers. An established robotic testing protocol was utilized to assess knee kinematics when the specimens were subjected to a 5-N·m internal rotation torque (0°-90° at 15° increments), a simulated pivot shift with 10-N·m valgus and 5-N·m internal rotation torque (15° and 30°), and an 88-N anterior tibial load (30° and 90°).

Results: Sectioning of the ACL led to significantly increased tibial internal rotation (from 0° to 90°) and anterior tibial translation (30° and 90°) as compared with the intact state. Significantly increased internal rotation occurred with further sectioning of the ALL (15°-90°) and Kaplan fibers (15°, 60°-90°). At higher flexion angles (60°-90°), sectioning the Kaplan fibers led to significantly greater internal rotation when compared with ALL sectioning. On simulated pivot-shift testing, ALL sectioning led to significantly increased internal rotation and anterior translation at 15° and 30°; sectioning of the Kaplan fibers led to significantly increased tibial internal rotation at 15° and 30° and anterior translation at 15°. No significant difference was found when anterior tibial translation was compared between the ACL/ALL- and ACL/Kaplan fiber–deficient states on simulated pivot-shift testing or isolated anterior tibial load.

Conclusion: The ALL and Kaplan fibers restrain internal rotation in the ACL-deficient knee. Sectioning the Kaplan fibers led to greater tibial internal rotation at higher flexion angles (60°-90°) as compared with ALL sectioning. Additionally, the ALL and Kaplan fibers contribute to restraint of the pivot shift and anterior tibial translation in the ACL-deficient knee.

Clinical Relevance: This study reports that the ALL and distal iliotibial band Kaplan fibers restrain anterior tibial translation, internal rotation, and pivot shift in the ACL-deficient knee. Furthermore, sectioning the Kaplan fibers led to significantly greater tibial internal rotation when compared with ALL sectioning at high flexion angles. These results demonstrate increased rotational knee laxity with combined ACL and anterolateral extra-articular knee injuries and may allow surgeons to optimize the care of patients with this injury pattern.

Keywords: anterior cruciate ligament; anterolateral rotational laxity; anterolateral ligament; iliotibial band; Kaplan fibers

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Residual anterolateral rotational laxity after anatomic anterior cruciate ligament (ACL) reconstruction has prompted investigators to reevaluate the role of anterolateral extra-articular knee structures. The anterolateral ligament (ALL) has received much attention because of the recharacterization of anterolateral knee anatomy,[2] although there are key historical references to this region of the knee.[22,25] The iliotibial band (ITB) is another important structure in this region, and Kaplan[9] eloquently described its anatomy in 1958, including firm attachments near the lateral femoral condyle now known as the "Kaplan fibers."

The anatomic structure and kinematic role of this region of the knee are relatively complex. These structures are believed to restrain tibial internal rotation, and their injury may be a contributing factor among patients with a high-grade pivot shift and those with a failed ACL reconstruction. In 1993, Terry et al[25] reported that concurrent iliotibial tract injury occurred among 93% of patients with an ACL tear. Aside from radiographic descriptions of the Segond fracture, some studies described soft tissue injuries to the anterolateral knee extra-articular structures in combination with ACL tears.[14,26] However, the diagnosis of an anterolateral knee injury is difficult in part because of a lack of clearly defined anatomic injury patterns and corresponding imaging findings, thereby limiting the ability to pair a reconstructive procedure to an anatomic injury pattern. According to a recent roundtable discussion, extra-articular augmentation of intra-articular ACL reconstructions may be indicated for athletes with high-grade pivot shift on clinical examination and for athletes engaging in pivoting sports.[15]

Several biomechanical studies recently focused on the kinematic role of the anterolateral knee in the setting of combined ACL deficiency.[8,11,16,17,19] Inconsistent sectioning protocols were performed: (1) isolated sectioning of the ALL and ITB, which allows assessment of their individual roles[11,17]; (2) combined sectioning of both structures,[8] which inhibits the ability to determine their individual roles; (3) detachment of the ITB and subsequent sectioning of the ALL, which may overestimate the role of the ALL[3,18,29]; and (4) isolated sectioning of the ALL without assessment of the ITB.[19,21,24] The findings of these investigations motivated the present study to compare the influence of these structures on knee stability in a paired knee design, supported by recently performed quantitative anatomic characterization of the ALL[10] and the distal ITB.[6]

The purpose of this study was to compare the role of the anterolateral knee structures—namely, the ALL and the ITB Kaplan fibers—in stabilizing the knee against tibial internal rotation, anterior tibial translation, and the pivot shift in ACL-deficient knees. We hypothesized that the Kaplan fibers would provide greater tibial internal rotation restraint than the ALL in ACL-deficient knees and that both structures would provide restraint against internal rotation on the pivot-shift maneuver.

METHODS

Specimen Preparation

Institutional review board approval was not required for this laboratory investigation, which utilized de-identified cadaveric specimens. The cadaveric specimens were obtained from a tissue bank and had been donated for the purpose of medical research. Ten paired (n = 20) male cadaveric knees were utilized for this study (mean age, 56 years; range, 48-62 years). Specimens without evidence of prior injury, surgical history, or gross anatomic abnormality were selected. Specimens were stored at –20°C and thawed at room temperature for 24 hours before preparation. The femoral and tibial diaphyses were sectioned 20 cm from the joint line; all soft tissues within 10 cm of the joint line were preserved; and the remaining soft tissues were removed to allow potting in polymethyl methacrylate.

Robotic Testing

Specimens were mounted in an inverted orientation in a custom fixture to a universal force-torque sensor (Delta F/T Transducer; ATI Industrial Automation) attached to the robotic end effector of a 6 degrees of freedom robotic system (KUKA KR 60-3; KUKA Robotics) (Figure 1).[21] Tibial internal rotation, anterior tibial translation, and simulated pivot-shift tests were performed. An internal rotation torque of 5 N·m was applied at 15° increments from 0° to 90° of knee flexion to evaluate tibial internal rotation. The pivot-shift test was simulated by a combined 5-N·m internal rotation torque and a 10-N·m valgus torque[4] and performed at 15° and 30° of knee flexion, and anterior tibial translation (measured at the most lateral aspect of the tibia) and tibial internal rotation were measured. Anterior tibial translation, measured at the center of the knee, was evaluated at 30° and 90° of knee flexion under an 88-N anterior tibial load. A 10-N joint compressive load was applied to the tibia throughout all tests to ensure tibiofemoral contact. The flexion angle was held constant during

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Figure 1. A left knee mounted in an inverted position in the robotic testing device, with the femoral end fixed to a universal force-torque sensor.

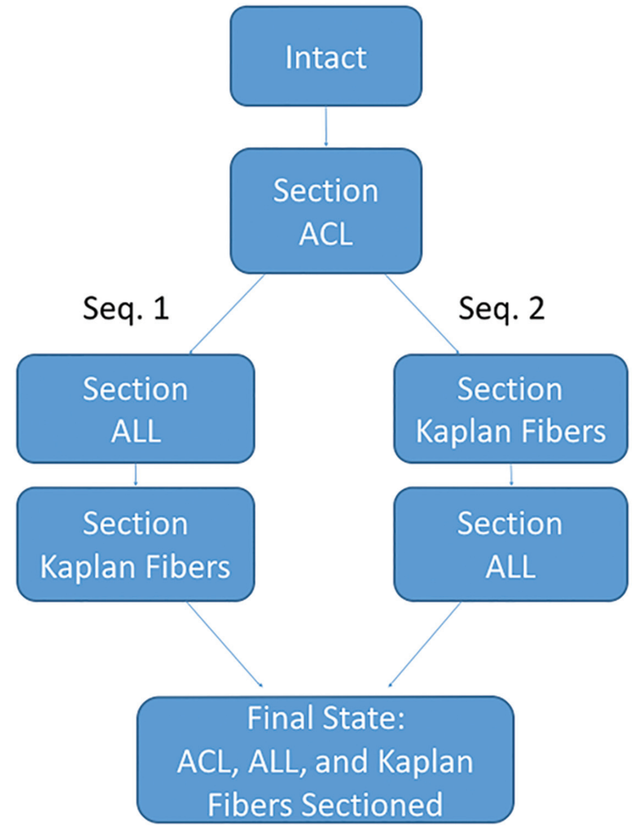

Figure 2. Specimen preparation for testing, including the states for randomly assigned sectioning: sequence 1, ALL before Kaplan; sequence 2, Kaplan before ALL. The final state consisted of sectioned ACL, ALL, and Kaplan. ACL, anterior cruciate ligament; ALL, anterolateral ligament; Kaplan, iliotibial band Kaplan fibers.

each test, while the other 5 degrees of freedom (internal/external rotation, varus/valgus rotation, anterior/posterior translation, medial/lateral translation, proximal/distal translation) were free to move naturally under the applied load and/or torque. The robotic testing protocol was performed as described for each specimen and condition.

Sectioning Protocol

Four scenarios were sequentially prepared and tested (Figure 2). A medial parapatellar arthrotomy was performed and subsequently closed with interrupted No. 2 nonabsorbable sutures (FiberWire; Arthrex Inc), and the robotic testing protocol was performed to record the kinematic pattern of the intact state of each specimen. Next, the ACL was sectioned and the arthrotomy similarly repaired. The robotic testing protocol was then performed to record the kinematic pattern of the ACL-deficient state. After the ACL-deficient state was tested, each knee in a pair was randomly assigned to 1 of 2 sequences: sequence 1, sectioning of the ALL before the Kaplan fibers; sequence 2, sectioning of the Kaplan fibers before the ALL (Figure 2).

Sectioning of the ALL was performed with the knee positioned at 75°. A longitudinal incision was made on the posterior aspect of the superficial layer of the ITB to identify the ALL attachment site on the tibia, midway between the Gerdy tubercle and the fibular head. The ALL was released from its tibial attachment at this location in accordance with quantitative anatomic descriptions[10] (Figure 3) and biomechanical studies.[19,21]

The proximal and distal Kaplan fibers were identified and sectioned at the posterolateral aspect of the distal femur. The proximal fibers were identified approximately 7 cm proximal to the joint line at the proximal ridge found along the diaphyseal-metaphyseal transition, while the distal fibers were found approximately 5 cm proximal to the joint line at the distal ridge found at the terminal extension of the supracondylar flare (Figure 4).[6,9]

Statistical Analysis

All measurement variables were normally distributed, so parametric statistical tools were used to make all comparisons among knee conditions. To address the hypotheses of this study, 6 a priori comparisons of interest were chosen (ie, before analysis was conducted) (Table 1; for the design of the experiment, see Figure 2). Paired *t* tests were used rather than repeated measures analysis of variance models owing to the different number of knees available for

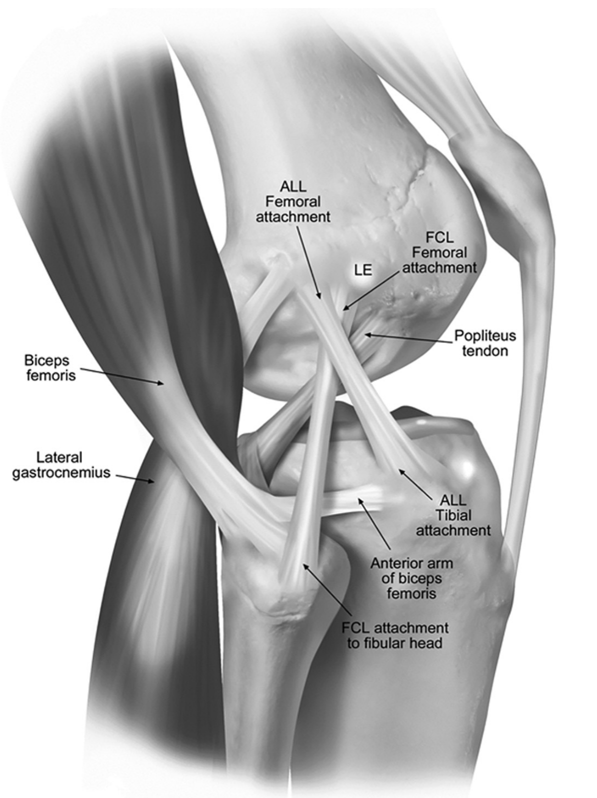

Figure 3. Right knee lateral structures with iliotibial band and capsule removed. ALL, anterolateral ligament; FCL, fibular collateral ligament; LE, lateral epicondyle. Reprinted with permission from Kennedy et al.[10]

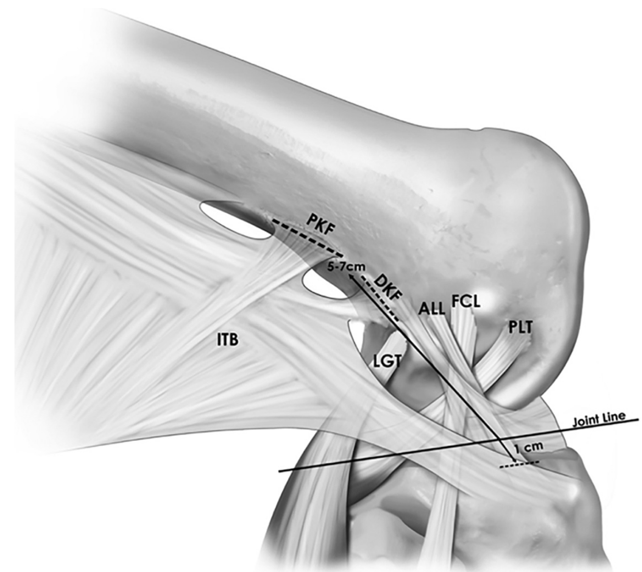

Figure 4. Right knee lateral structures depicting sectioning of the Kaplan fibers off the femur (dashed lines). ALL, anterolateral ligament; DKF, distal Kaplan fibers; FCL, fibular collateral ligament; ITB, iliotibial band; LGT, lateral gastrocnemius tendon; PKF, proximal Kaplan fibers; PLT, popliteus tendon. Adapted with permission from Godin et al.[6]

comparisons of interest. The Holm-Bonferroni method was used to adjust P values for multiple comparisons within each simulated biomechanical test and flexion angle. Adjusted P values $<.05$ were deemed statistically significant. Based on an assumption of 2-tailed t testing, an alpha of .05, and a power requirement of 80%, 10 matched pairs of knees were sufficient to detect effect sizes (Cohen d) of 1 and 0.66 for comparisons of 10 and 20 knees, respectively. The statistical software R was used for all analyses (R Foundation for Statistical Computing with ggplot2).

TABLE 1
A Priori Comparisons of Sectioned Structure States Made via Paired t Tests[a]

Comparison	Knees, n[b]
Intact vs ACL	18
ACL vs ACL + ALL	9
ACL vs ACL + Kaplan	9
ACL + ALL vs ACL + Kaplan	9[c]
ACL + ALL vs ACL + ALL + Kaplan	9
ACL + Kaplan vs ACL + ALL + Kaplan	9

[a]ACL, anterior cruciate ligament; ALL, anterolateral ligament; Kaplan, iliotibial band Kaplan fibers.
[b]Repeated measures comparison on the same knees, unless noted otherwise.
[c]Matched pairs.

RESULTS

Specimen Preparation

There was no gross evidence of abnormality upon inspection of the cruciate ligaments, menisci, or cartilage. The ACL and anterolateral structures were intact in all pairs. The data from all 10 knee pairs (n = 20 knees) were reviewed. Upon initial data analysis, pair 4 had >2 times the standard deviation of change in the kinematic properties after sectioning of the Kaplan fibers as compared with the other 9 pairs. This phenomenon was not appreciated until data analysis; no clear specimen or testing inconsistencies were identified on review. A judgment was made to define pair 4 as an outlier and remove it from the analysis.

Tibial Internal Rotation With Applied Internal Rotation Torque

ACL sectioning resulted in significantly increased internal rotation at all flexion angles (Figure 5, Table 2). Subsequent sectioning of the Kaplan fibers led to a significant increase in internal rotation of 1.6° (P = .011) at 60°, 2.1° (P = .004) at 75°, and 2.2° (P = .003) at 90°. ALL sectioning in ACL-deficient knees (and intact Kaplan fibers) resulted in significantly increased internal rotation at all flexion

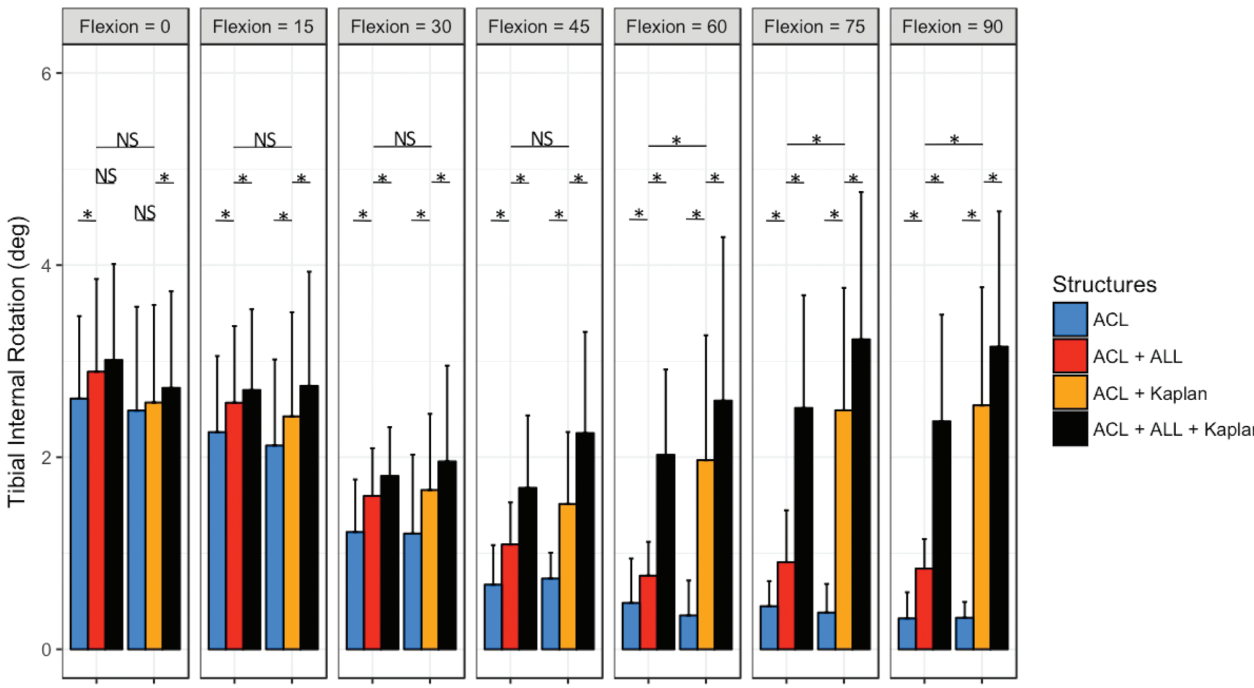

Figure 5. Mean tibial internal rotation (intact values subtracted) for tested conditions at knee flexion angles 0° to 90°. Selected statistical comparisons are noted with a horizontal line connecting the 2 bars. *$P < .05$. ACL, anterior cruciate ligament; ALL, anterolateral ligament; Kaplan, iliotibial band Kaplan fibers; NS, not significant ($P > .05$). Error bar indicates 1 SD.

TABLE 2
Tibial Internal Rotation for Sequences 1 and 2 for Each Condition With Applied Internal Rotation Torque[a]

	Knee Flexion Angle, Mean ± SD, deg						
Sectioned Structures	0°	15°	30°	45°	60°	75°	90°
Sequence 1							
Intact	8.9 ± 2.5	15.6 ± 3.5	20.4 ± 4.3	21.7 ± 4.7	21.4 ± 4.9	20.3 ± 4.7	20.1 ± 4.3
ACL	11.6 ± 3.1	17.9 ± 3.9	21.7 ± 4.5	22.4 ± 4.8	21.8 ± 5.0	20.8 ± 4.8	20.4 ± 4.3
ACL + ALL	11.8 ± 3.1	18.2 ± 4.0	22.0 ± 4.5	22.8 ± 4.9	22.1 ± 5.0	21.2 ± 4.8	20.9 ± 4.3
ACL + ALL + Kaplan	12.0 ± 3.2	18.3 ± 4.1	22.2 ± 4.5	23.4 ± 4.9	23.4 ± 5.1	22.8 ± 4.9	22.5 ± 4.3
Sequence 2							
Intact	9.8 ± 2.5	15.8 ± 3.2	20.7 ± 4.8	22.0 ± 6.3	21.6 ± 8.0	20.4 ± 8.6	19.8 ± 8.7
ACL	12.3 ± 3.1	17.9 ± 3.4	21.9 ± 4.8	22.7 ± 6.3	21.9 ± 8.1	20.8 ± 8.7	20.2 ± 8.6
ACL + Kaplan	12.4 ± 3.1	18.3 ± 3.4	22.3 ± 4.8	23.5 ± 6.3	23.5 ± 7.8	22.9 ± 8.8	22.4 ± 9.1
ACL + Kaplan + ALL	12.5 ± 3.1	18.6 ± 3.4	22.6 ± 4.8	24.3 ± 6.2	24.2 ± 7.7	23.6 ± 8.8	23.0 ± 9.0

[a]ACL, anterior cruciate ligament; ALL, anterolateral ligament; Kaplan, iliotibial band Kaplan fibers.

angles except 0°. Importantly, sectioning the Kaplan fibers led to significantly greater internal rotation than ALL sectioning at higher flexion angles (60°, 75°, 90°), but there was no difference at lower flexion angles (0°, 15°, 30°, 45°).

Simulated Pivot Shift: Tibial Internal Rotation

ACL sectioning led to significantly increased tibial internal rotation at 15° and 30° (Figure 6, Table 3). At 15° and 30°, subsequent sectioning of the ALL increased internal rotation by 0.4° (P = .001) and 0.4° ($P < .001$), respectively, while sectioning of the Kaplan fibers resulted in significantly increased internal rotation of 0.4° (P = .012) and 0.5° (P = .024) in ACL-deficient knees. There was no significant difference in internal rotation when the ACL/ALL-sectioned state was compared with the ACL/Kaplan fiber–sectioned state at 15° or 30°. Subsequent sectioning to include the ALL and Kaplan fibers significantly increased internal rotation at 15° and 30°.

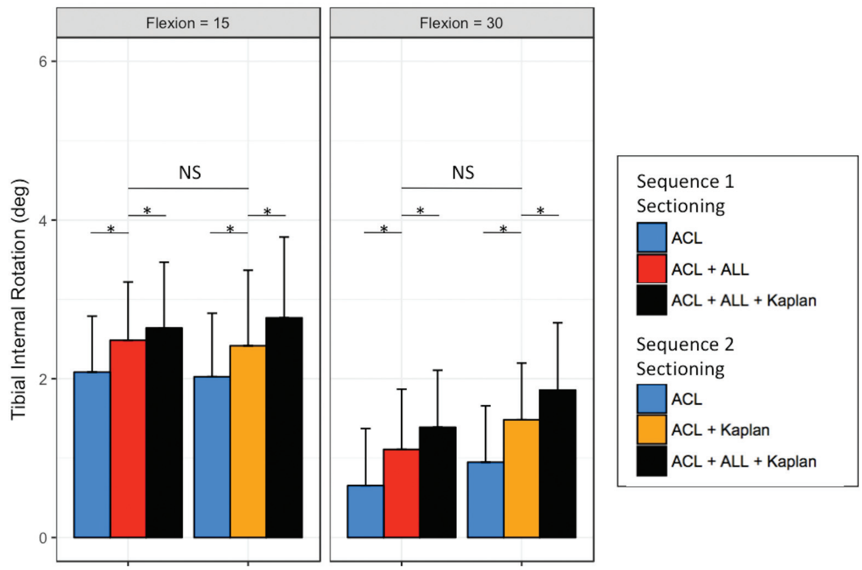

Figure 6. Mean tibial internal rotation (intact values subtracted) during a simulated pivot shift for tested conditions at knee flexion angles 15° and 30°. Selected statistical comparisons are noted with a horizontal line connecting the 2 bars. $^{*}P < .05$. ACL, anterior cruciate ligament; ALL, anterolateral ligament; Kaplan, iliotibial band Kaplan fibers; NS, not significant ($P > .05$). Error bar indicates 1 SD.

Simulated Pivot-Shift Test: Anterior Tibial Translation

ACL sectioning led to significantly increased anterior tibial translation during a simulated pivot shift at 15° and 30° (Figure 7, Table 3). The addition of ALL sectioning in the setting of ACL deficiency increased anterior tibial translation by 0.4 mm at 15° (P = .003) and 0.5 mm at 30° ($P <$ .001). Similarly, the addition of Kaplan fiber sectioning in the setting of ACL deficiency increased anterior tibial translation by 0.3 mm at 15° (P = .032) and 0.6 mm at 30° ($P > .05$). There was no significant difference in anterior tibial translation when the ACL/ALL- and ACL/Kaplan fiber–sectioned states were compared at 15° and 30° during a simulated pivot shift. Subsequent sectioning to include the ALL and Kaplan fibers significantly increased anterior tibial translation at 15° and 30°.

Anterior Tibial Translation With Applied Anterior Load

ACL sectioning led to significantly increased anterior tibial translation at 30° and 90° (Figure 8, Table 4). The addition of ALL sectioning in ACL-deficient knees resulted in a small but significant increase in anterior tibial translation 0.3 mm at 30° ($P < .001$) and 90° (P = .008). Kaplan fiber sectioning in ACL-deficient knees also resulted in a small but significant increase in anterior tibial translation of 0.2 mm at 30° (P = .047) and 0.9 mm at 90° (P = .008). However, there was no significant difference in anterior tibial translation when the ACL/ALL-sectioned state was compared with the ACL/Kaplan fiber–sectioned state at 30° or 90°.

The addition of ALL sectioning in the setting of the ACL/Kaplan fiber–sectioned state did not significantly increase anterior tibial translation. However, the addition of Kaplan fiber sectioning in the setting of the ACL/ALL-sectioned state resulted in significantly increased anterior tibial translation at 90° (0.6 mm, P = .016) but not 30°.

TABLE 3
Tibial Internal Rotation and Anterior Tibial Translation During Simulated Pivot-Shift Test[a]

	Knee Flexion Angle, Mean ± SD	
Sectioned Structures	15°	30°
Tibial internal rotation, deg		
Sequence 1		
Intact	15.8 ± 3.5	21.0 ± 4.3
ACL	17.8 ± 3.9	21.7 ± 4.5
ACL + ALL	18.2 ± 4.0	22.1 ± 4.5
ACL + ALL + Kaplan	18.4 ± 4.1	22.4 ± 4.5
Sequence 2		
Intact	16.1 ± 3.3	21.3 ± 4.8
ACL	18.1 ± 3.5	22.3 ± 4.9
ACL + Kaplan	18.5 ± 3.5	22.8 ± 4.9
ACL + Kaplan + ALL	18.8 ± 3.6	23.2 ± 4.8
Anterior tibial translation, mm		
Sequence 1		
Intact	13.6 ± 3.7	18.7 ± 4.5
ACL	19.5 ± 4.6	22.9 ± 5.2
ACL + ALL	19.9 ± 4.7	23.4 ± 5.2
ACL + ALL + Kaplan	20.1 ± 4.8	23.8 ± 5.2
Sequence 2		
Intact	14.8 ± 2.9	19.9 ± 4.4
ACL	20.4 ± 3.5	24.2 ± 4.6
ACL + Kaplan	20.7 ± 3.5	24.8 ± 4.6
ACL + Kaplan + ALL	21.2 ± 3.6	25.4 ± 4.6

[a]Results are stratified by sequence, testing condition, and knee flexion angle. ACL, anterior cruciate ligament; ALL, anterolateral ligament; Kaplan, iliotibial band Kaplan fibers.

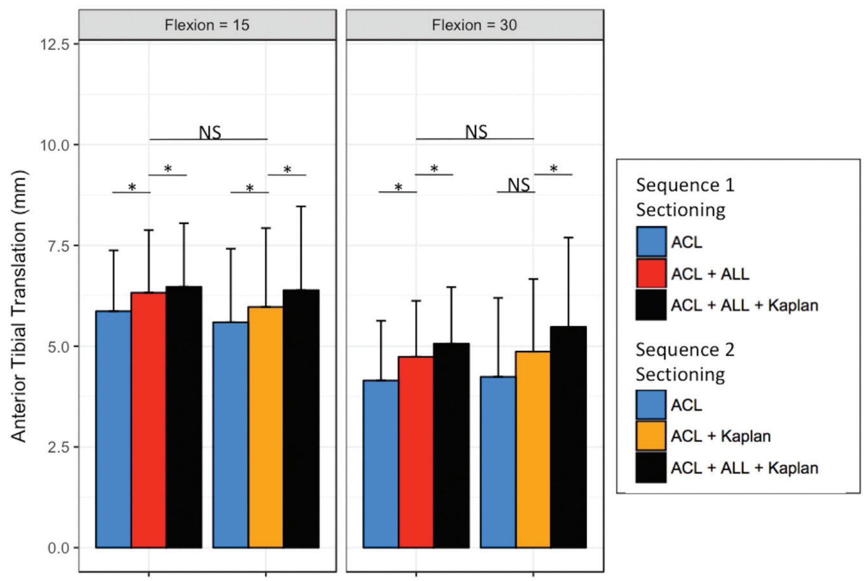

Figure 7. Mean anterior tibial translation (intact values subtracted) during a simulated pivot shift for tested conditions at knee flexion angles 15° and 30°. Selected statistical comparisons are noted with a horizontal line connecting the 2 bars. *$P < .05$. ACL, anterior cruciate ligament; ALL, anterolateral ligament; Kaplan, iliotibial band Kaplan fibers; NS, not significant ($P > .05$). Error bar indicates 1 SD.

TABLE 4
Anterior Tibial Translation Reported for Sequences 1 and 2 for Each Condition on Anterior Drawer Testing (30° and 90°)[a]

	Knee Flexion Angle, Mean ± SD, mm	
Sectioned Structures	30°	90°
Sequence 1		
Intact	6.0 ± 2.8	4.9 ± 2.2
ACL	16.4 ± 4.5	10.6 ± 2.9
ACL + ALL	16.7 ± 4.4	10.9 ± 2.9
ACL + ALL + Kaplan	16.9 ± 4.5	11.5 ± 2.9
Sequence 2		
Intact	6.1 ± 1.3	4.6 ± 1.6
ACL	15.8 ± 3.1	10.1 ± 3.4
ACL + Kaplan	16.0 ± 3.0	11.0 ± 3.7
ACL + Kaplan + ALL	16.3 ± 3.1	11.3 ± 3.7

[a]ACL, anterior cruciate ligament; ALL, anterolateral ligament; Kaplan, iliotibial band Kaplan fibers.

DISCUSSION

The most important finding of this study was the presence of an individual and additive effect of ALL and Kaplan fiber sectioning that resulted in significantly increased internal rotation, pivot shift, and anterior translation at most flexion angles in ACL-deficient knees. Furthermore, sectioning the Kaplan fibers led to significantly greater internal rotation when compared with ALL sectioning at higher flexion angles (60°-90°) as the role of the ACL in controlling internal rotation diminished. Together, these findings suggest that anterolateral knee injuries contribute to increased tibial internal rotation, pivot shift, and anterior tibial translation in the setting of ACL deficiency.

While statistical significance was identified for many comparisons, it is important to assess the potential clinical relevance of these findings. Internal rotation is difficult to measure precisely on physical examination, although as little as 1.4° of increased internal rotation was associated with patient-reported functional limitations and an inability to return to one's desired sport after an ACL injury.[23] Several biomechanical investigations demonstrated that ACL reconstruction alone in the setting of combined ACL and anterolateral knee injuries failed to restore native knee kinematics.[8,11,20,21] These findings suggest that isolated ACL reconstruction for combined injuries may contribute to residual rotational laxity in a subset of patients.

In the present study, the ALL and Kaplan fibers had a significant role in restraining isolated tibial internal rotation, especially at higher flexion angles. This suggests a reciprocal role of the ACL and anterolateral structures for restraint of tibial internal rotation, with the ACL dominant at low flexion angles (0°, 15°, 30°) and the anterolateral structures dominant at higher flexion angles (45°, 60°, 75°, 90°). At 45°, 60°, 75°, and 90°, the absolute increase in internal rotation was greater after combined ALL and Kaplan fiber sectioning in the setting of ACL deficiency as compared with isolated ACL sectioning. In application of the 1.4° threshold for residual clinical symptoms as described earlier, a potentially clinically meaningful effect of sectioning the ALL and Kaplan fibers was found from 60° to 90°. Similarly, pivot-shift testing revealed a comparable role for the ALL/Kaplan fibers in restraining internal rotation at 15° and 30° when compared with isolated ACL

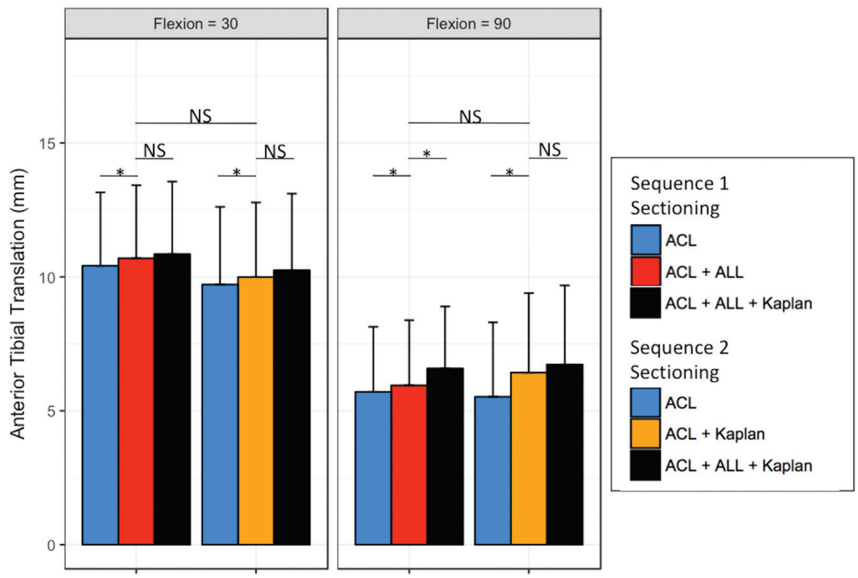

Figure 8. Anterior tibial translation (intact values subtracted) for tested conditions at knee flexion angles 30° and 90°. Selected statistical comparisons are noted with a horizontal line connecting the 2 bars. $*P < .05$. ACL, anterior cruciate ligament; ALL, anterolateral ligament; Kaplan, iliotibial band Kaplan fibers; NS, not significant ($P > .05$). Error bar indicates 1 SD.

sectioning. Therefore, the anterolateral structures may have a clinically relevant role in restraining internal rotation and pivot shift in a codominant manner. To better understand the role for combining ACL reconstruction with lateral extra-articular procedures, improved objective injury diagnosis is needed, as well as randomized trials among patients with objectively verified combined injuries to the ACL and anterolateral structures.

Continued attention to the anterolateral region of the knee is warranted, as injuries to these structures occur frequently in combination with ACL tears and these combined injuries may result in increased anterolateral rotational laxity.[1,2,5,7,12,14,25,26] Thus, in addition to careful evaluation for meniscal injuries (ie, posterior root tears and ramp lesions), patients with ACL tears and a high-grade pivot shift should be further evaluated for concomitant injuries of the anterolateral structures, which could contribute to this increased rotational laxity.

Our findings revealed that sectioning the Kaplan fibers resulted in significantly increased internal rotation at higher flexion angles (60°, 75°, 90°) when compared with the ALL, whereas there was no significant difference at lower flexion angles (0°, 15°, 30°, 45°). These findings suggest that the ITB (via the Kaplan fibers) is an important extra-articular stabilizer for internal rotation at high flexion angles in the setting of ACL deficiency and that the ALL plays a lesser, secondary role. The clinical significance of this dominant role for the Kaplan fibers at higher flexion angles is not entirely certain, although a reciprocal relationship in tibial internal rotation restraint was demonstrated with ACL dominance at low flexion angles and with Kaplan fiber dominance at high flexion angles.

Other studies have also indicated the importance of the ITB in restraining internal rotation.[11,13,28] A recent study by Vap et al[27] demonstrated the relevant roles of the distal ITB and the ALL–lateral capsule complex. When the distal ITB was sectioned before the ALL–lateral capsule complex, the observed changes were greater than those observed when the ALL–lateral capsule complex was sectioned before the distal ITB. In their study, the distal ITB was the major restraint for internal rotation at higher flexion angles in ACL-intact knees. Although the present study evaluated the role of the ITB (via the Kaplan fibers) in ACL-deficient knees, a similar role for the ITB in restraining internal rotation at high flexion angles was found. Lutz et al[13] observed that tension on the Kaplan fibers increased during internal rotation and suggested a stabilizing role.

The role of the ALL in controlling internal rotation has been a major subject of interest in recent years. The present study revealed that the ALL restrains tibial internal rotation at all flexion angles; additionally, the ALL played a role in restraining anterior tibial translation during the pivot-shift and anterior drawer testing in ACL-deficient knees. Other studies reported that the ALL has a significant role in controlling internal rotation in ACL-deficient knees.[18,19] However, the functional significance of the ALL has also been questioned. In a recent biomechanical study evaluating the roles of the knee anterolateral structures, Kittl et al[11] reported a significant role for the ITB superficial and deep layers in restraining tibial internal rotation but only a minimal contribution for the ALL and anterolateral capsule. Noyes et al[17] also reported a more prominent role of the ITB versus the ALL in ACL-deficient knees on anterior tibial loading, internal rotation, and pivot-shift testing. However, in their study, the ITB was completely released off the Gerdy tubercle, potentially limiting the clinical relevance of this scenario. Spencer et al[24] evaluated the influence of sectioning the ALL in ACL-deficient knees and found small but significant increases in internal rotation, anterior translation, and pivot-shift test grades.

The intricate relationship of the anterolateral structures leads to a technically challenging dissection and may contribute to the variability in sectioning protocols that have been performed.[8,11,17-19,21,24] For example, in a recent study by Inderhaug et al,[8] combined sectioning of the ALL and ITB proximal and distal femoral attachments (ie, Kaplan fibers, although not explicitly stated) led to increased anterior tibial translation and internal rotation, although the individual roles of the ALL and ITB were not compared with their study design. More than 20 years ago, Samuelson et al[20] investigated the influence of the anterolateral structures in ACL-deficient knees and reported increased anterior translation and internal rotation in combined injuries as compared with isolated ACL deficiency.

Internal rotation is often the focus of studies on anterolateral knee injuries; however, these structures may also influence anterior tibial translation. In the present study, significantly increased anterior tibial translation on isolated anterior tibial loading at 30° and 90° and pivot-shift testing at 15° or 30° was observed when the ALL was sectioned. Similarly, sectioning of the Kaplan fibers led to increased anterior tibial translation on pivot-shift testing at 15° as well as on anterior tibial loading at 30° and 90°. However, these increases in anterior tibial translation in the ACL-deficient knee were small (all <1.0 mm), and there were no significant differences between the ACL/Kaplan fiber– and the ACL/ALL-deficient states on anterior tibial translation. Combined sectioning of the ALL and Kaplan fibers led to greater anterior tibial translation than isolated sectioning of either structure and may reflect clinically significant changes that could occur with severe injury to the anterolateral knee. Terry et al[25] reported an increase in anterior tibial translation during the Lachman test in ACL-deficient knees with a concomitant injury to the biceps–capsulo-osseous iliotibial tract confluence, suggesting a clinically relevant role for the anterolateral structures in restraining anterior tibial translation. In contrast, however, previous studies did not demonstrate significant changes in anterior tibial translation when either the ALL or the ITB was sectioned.[11,18,19,21]

This study was designed to further characterize the native properties of key anterolateral knee structures. It was a controlled laboratory study, and paired fresh-frozen cadaveric knees were used to allow comparison of the role of the ALL and Kaplan fibers. Unlike some protocols that require removal of the skin, muscle, and soft tissues down to the level of the ligaments and capsule, these tissues were left intact, and surgical approaches were closed before each testing interval to minimize potential confounding effects. Additionally, a validated and highly accurate and repeatable 6 degrees of freedom robotic system was utilized.

Limitations associated with this study were identified. This was a biomechanical time-zero study with surgically created defects that may not fully reflect laxity associated with acute injuries or soft tissue attenuation that may occur in chronic injuries. Furthermore, in vivo conditions, including joint compression, dynamic loading, and muscle contraction, cannot be fully reproduced in cadaveric biomechanical studies.

CONCLUSION

The ALL and Kaplan fibers both restrain internal rotation in the ACL-deficient knee. Sectioning the Kaplan fibers led to greater tibial internal rotation at higher flexion angles (60°-90°) as compared with ALL sectioning. Additionally, the ALL and Kaplan fibers both contribute to restraint of the pivot shift and anterior tibial translation in the ACL-deficient knee.

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