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Influence of the injury to the Kaplan fibers of the iliotibial band on anterolateral rotatory knee laxity in the anterior cruciate ligament injury -a retrospective cohort study-

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1 **Influence of the injury to the Kaplan fibers of the iliotibial band on anterolateral**
2 **rotatory knee laxity in the anterior cruciate ligament injury - a retrospective cohort**
3 **study**

Influence of the injury to the Kaplan fibers of the iliotibial band on anterolateral rotatory knee laxity in the anterior cruciate ligament injury - a retrospective cohort study

Abstract

Background: Biomechanical cadaveric studies have shown that Kaplan fibers (KF) of the iliotibial band play a role in controlling anterolateral rotatory knee laxity in anterior cruciate ligament (ACL) injury. However, in the clinical setting, the contribution of injury to KF on anterolateral rotatory laxity remains unclear.

Purpose: To investigate the effect of MRI-detected concomitant injury to KF in ACL injured knees on anterolateral rotatory laxity measured by pivot-shift test in the clinical setting.

Study Design: Case-control study; Level of evidence, 3.

Methods: Ninety-one patients with primary ACL tears (age: 25 ± 11 years, 46 male/45 female) whose MRI was taken within 90 days after injury, were enrolled. KF injury was assessed by MRI according to the previously reported criteria, and the subjects were allocated into KF injury group and non-KF injury group. At the time of ACL reconstruction, the pivot-shift test was performed under anesthesia and quantitatively evaluated by tibial acceleration using an electromagnetic measurement system. Manual grading of the pivot-shift test was also assessed according to the IKDC guidelines. These were statistically compared between two groups using Mann-Whitney U test and Fisher's exact test ($p < 0.05$).

Results: KF was identified in 85 patients (93.4%), and KF injury was detected in twenty patients out of

23 85 patients (23.5%). No significant differences were observed between KF injury group (n = 20) and non-
24 KF injury group (n = 65) in demographic data, the period from injury to MRI (8.0 ± 14.0 vs. 8.9 ± 12.1
25 days), the rate of meniscal injury (50.0% vs. 53.8%), or the rate of anterolateral ligament injury (45.0%
26 vs. 44.6%). Regarding the pivot-shift test, no significant differences were observed in tibial acceleration
27 (1.2 [interquartile range, IQR: 0.5 - 2.1] m/s^2 vs. 1.0 [IQR: 0.6 - 1.7] m/s^2) or manual grading between two
28 groups.

29 **Conclusion:** Concomitant KF injury did not significantly affect the pivot-shift phenomenon in acute ACL-
30 injured knees. The findings suggest that the contribution of KF injury to anterolateral rotatory knee laxity
31 may be limited in the clinical setting.

32 **Key terms:** anterior cruciate ligament; anterolateral complex; iliotibial band; Kaplan fibers; magnetic
33 resonance imaging; pivot-shift; anterolateral rotatory knee laxity
34

35 **What is known about the subject:** Biomechanical studies have shown contribution of the Kaplan
36 fibers to anterolateral rotatory laxity while one recent clinical study has reported that KF injury was
37 not associated with higher-grade pivot-shift test assessed by manual grading in ACL injury.
38

39 **What this study adds to existing knowledge:** The present study showed that concomitant KF injury
40 did not significantly affect the pivot-shift phenomenon in acute ACL-injured knees by quantifying the

41 pivot-shift test using an electromagnetic measurement system. The present findings suggest that the
42 contribution of KF injury to anterolateral rotatory knee laxity may be limited in the clinical setting.

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Introduction

Recently, much debate ensued regarding the biomechanical function of the anterolateral complex (ALC) of the knee in anterior cruciate ligament (ACL) injured knees after potential impact of ALC injury on anterolateral rotatory laxity has been extensively discussed in the setting of ACL injury.^{12,37,41,51} The ALC consists of the superficial and deep aspects of the iliotibial band (ITB) with its Kaplan fiber attachments on the distal femur, along with the anterolateral ligament (ALL), a capsular structure within the anterolateral capsule, according to the statements from the International ALC Consensus Group Meeting.²¹ The distal femoral attachment of the ITB was originally identified by Kaplan in 1958³⁴ and later known as the ‘Kaplan fibers (KF)’.⁹ Anatomic studies found that KF were the transverse fibers attached to the femoral metaphysis and in close proximity to the branches of the superior genicular artery, and in recent years, it has been reported that the KF have two distinct bundles attached proximally and distally.^{23,26} KF and their injuries can be identified on MRI,^{8,9} and the rate of the concomitant KF injury in ACL tear has been reported to be 17.6–60%.^{9,10,13,15,40,45} Recent biomechanical studies have indicated that KF may function as a secondary restraint in the ACL-deficient knees,^{27,36} and one cadaveric study reported that KF played a greater role in tibial internal rotation at higher flexion angle than the ALL.²⁰ These biomechanical studies^{20,27,36} using cadaveric knees have shown the contribution of KF to anterolateral rotatory laxity in the ACL-injured knees. However, one recent clinical study has shown that KF injuries were not associated with a higher-grade pivot-shift in acute ACL injuries;¹³ thus the role of KF in controlling anterolateral

62 rotatory knee laxity remains uncertain. ACL reconstruction combined with either ALL reconstruction or
63 lateral extra-articular tenodesis may better restore anterolateral rotatory knee laxity and decrease the
64 failure rate,^{6,22,43,48} but there is not such evidence for KF repair/reconstruction so far.

65 In the clinical setting, the pivot-shift test is a valuable manual examination to detect anterolateral
66 rotatory knee laxity^{19,39} although this assessment is subjective and widely variable. Additionally, the pivot-
67 shift test is multifactorial, and can be influenced by ALC lesions, meniscal tears, posterior tibial slope and
68 other osseous parameters.¹⁸ Importantly, the pivot-shift has been shown to correlate with functional
69 outcomes after ACL reconstruction⁷ although there is not always a complete correlation between
70 biomechanical instability and clinical inferior outcomes. Recently, there are some clinically usable and
71 validated quantitative evaluation systems for assessing rotatory knee laxity during the pivot-shift
72 test,^{29,31,42,44} and the electromagnetic measurement system (EMS) has been shown to have high diagnostic
73 reliability for the pivot-shift test.⁴⁴ The pivot-shift phenomenon can be quantitatively measured as tibial
74 acceleration (m/s^2) using the EMS.

75 Thus, the purpose of the present study was to investigate the effect of MRI-detected concomitant
76 injury to KF in acute ACL-injured knees on pivot-shift test measured by the EMS in the clinical setting.
77 It was hypothesized that the acute ACL-injured knees with concomitant KF injury would increase tibial
78 acceleration and have higher grade of manual pivot-shift test compared to the ACL-injured knees without
79 concomitant KF injury.

Materials and methods

Subjects

The present retrospective analysis of prospectively collected data included a total of 91 patients (46 males/45 females; mean age 25 ± 11 years) with unilateral acute primary ACL tear, who underwent primary ACL reconstruction in one institution. The diagnosis of the ACL tears was made based on clinical findings and MRI, which was confirmed arthroscopically. The inclusion criteria were as follows; unilateral acute primary ACL tears; time from injury to MRI < 90 days;⁹ preoperative evaluation using the EMS. The exclusion criteria were as follows: concomitant ligament procedures (medial collateral ligament, posterior cruciate ligament, and/or posterolateral complex) or realignment procedures; contralateral knee injury; previous injury or surgery in ipsilateral knee; more than one-year period from MRI to the surgery; MRI quality was less than 1.5-T; insufficient data of the EMS measurement. Originally, 239 patients were identified from the medical records from March 2013 to September 2020. After reviewing inclusion and exclusion criteria, a total of 91 patients were enrolled in the present study (**Figure 1**). The study was approved by the Institutional Review Board of Kobe University (ID No. B190055).

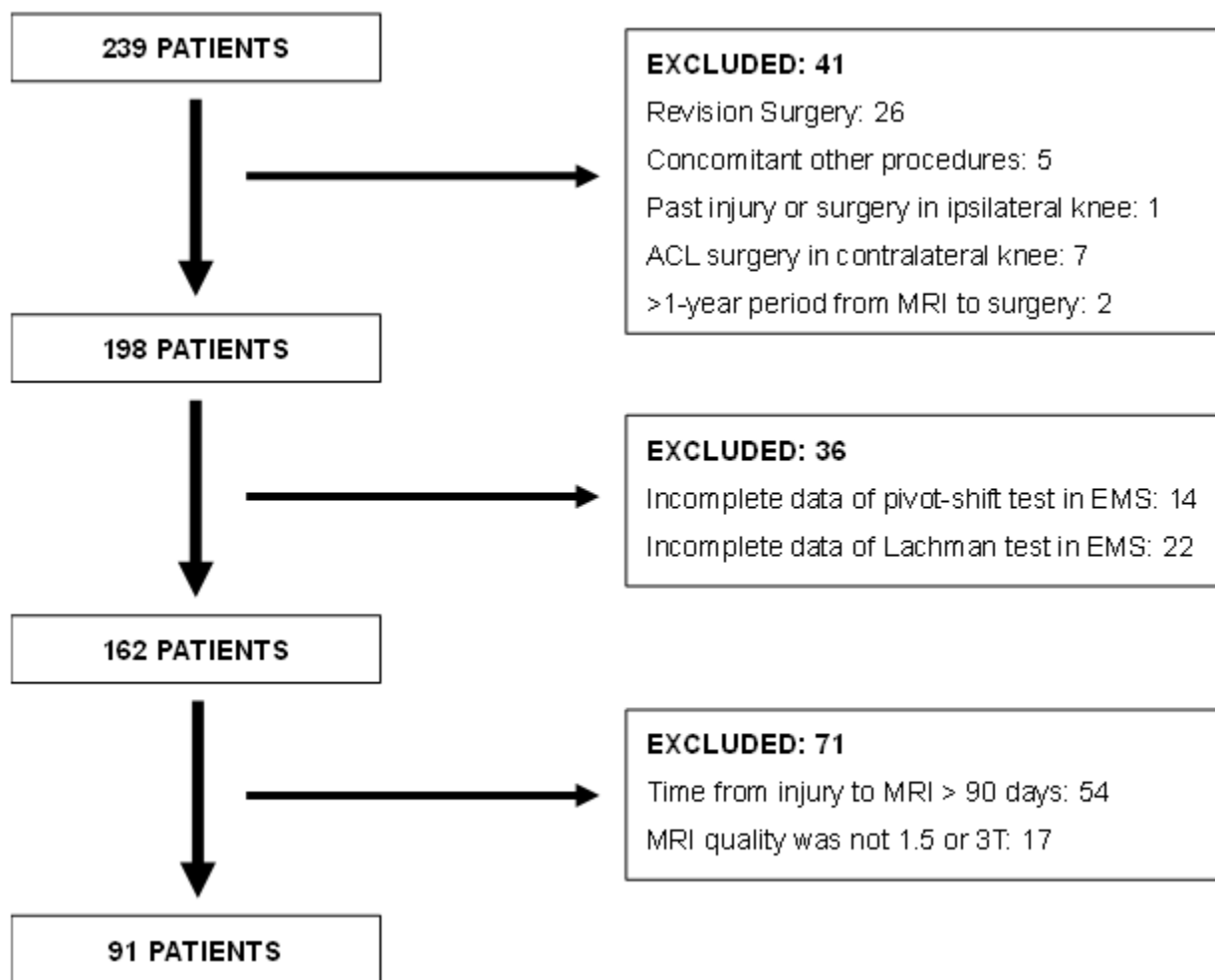


Figure 1. Flowchart of the inclusion/exclusion process for the present study

ACL, anterior cruciate ligament; MRI, magnetic resonance imaging; EMS, electromagnetic measurement system; KF, Kaplan fibers.

Identification of concomitant KF injury

Concomitant KF injury was identified using 1.5-T or 3.0-T MRI which was taken for the diagnosis of ACL injury. Knee MRI was performed in the supine position with the leg extended. Three-plane (sagittal,

105 coronal and axial) sequences using both proton-density-weighted images and fat-suppressed proton-
106 density-weighted images were obtained. KF injury was assessed according to the previous report by Batty
107 et al.⁹ by a single examiner (an orthopaedic surgeon) after confirming the inter-rater reliability. Briefly,
108 the diagnosis of injury to the KF required at least 1 direct sign of injury or at least 2 indirect signs in any
109 plane. The direct signs included (1) discontinuity of the KF and (2) femoral avulsion of the KF; Indirect
110 signs included (1) thickening and/or intrasubstance signal change of the KF, (2) focal bone marrow edema
111 at KF insertion site (posterolateral femur), (3) localized soft tissue edema in the region of the KF, and/or
112 (4) wavy appearance to the KF.⁹

113 The examiner was blinded to the results of the pivot-shift evaluations. Based on the MRI findings, the
114 patients were allocated into two groups: KF injury group and the non-KF injury group. The manual
115 grading and the quantitative evaluations of the pivot-shift test were compared between two groups.

116

117 **Assessment of the concomitant injury of meniscus, collateral ligament and ALL**

118 The meniscal injury was diagnosed by MRI and arthroscopy during the surgery, and the collateral ligament
119 injuries were diagnosed based on MRI and clinical examination. The ALL injury was assessed by MRI
120 using the previously reported method.¹⁴ All results were blinded at the time of pivot-shift evaluation.

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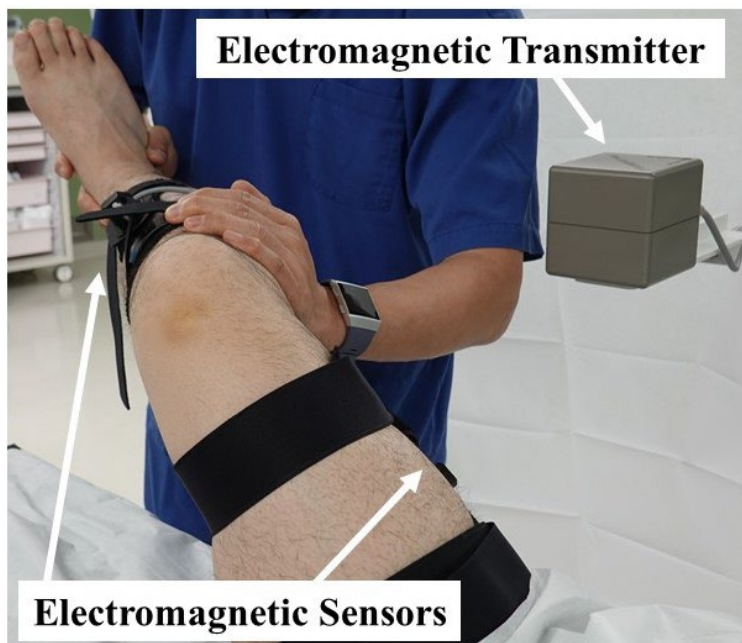
122 **Measurement of the pivot-shift test and Lachman test**

Pivot-shift test and Lachman test were performed under general anesthesia just prior to ACL reconstruction. The standardized pivot-shift test was performed by experienced surgeons as previously reported.²⁸ For the quantitative evaluation of pivot-shift test, tibial acceleration was measured using the originally developed EMS (JIMI Kobe, Arthrex Japan, Tokyo, Japan) as previously described^{2,30,31,44} (**Figure 2**). In addition, Lachman test was also measured using the EMS, and side-to-side difference (SSD) in anterior tibial translation (mm) was calculated by subtracting the value in the contralateral knee from the value in the injured knee as previously reported.³

Briefly, two electromagnetic sensors were secured on the thigh and shank with plastic straps. Seven anatomic bony landmarks of the femur and tibia (greater trochanter, medial and lateral epicondyles, the crossing point of medial joint line and the medial collateral ligament, fibular head and the medial and lateral malleoli) were digitized with a probe with a sensor to register three-dimensional positions of the landmarks in relation to the two sensors. The positions of the femur and tibia were then recognized based on the spatial relationship between the anatomic bony landmarks and sensors. The anatomic coordinates of the knee were set according to the system proposed by Grood and Suntay.²⁴ The six degree-of-freedom knee kinematics were recorded during the pivot-shift test with a sampling rate of 240 Hz. Tibial acceleration (m/s^2) at the time of posterior reduction of the tibia was then calculated from the data of the tibial anteroposterior translation. For the accuracy of this measurement, it is reported that the average standard deviation of three repeated measurements was $0.2 \pm 0.1 \text{ m/s}^2$.^{30,31,44}

141 At the same time, manual grade of the pivot-shift test was assessed according to the International
142 Knee Documentation Committee (IKDC) guidelines³³, and categorized as low grade (IKDC grade 0 and
143 1) and high grade (IKDC grade 2 and 3). The manual grading was performed blinded to the quantitative
144 evaluation result.

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147 **Figure 2.** The electromagnetic measurement system for the pivot-shift test. Two electromagnetic sensors
148 were secured on the thigh and shank with plastic straps. The anatomic coordinates of the knee were set
149 via electromagnetic transmitter. The acceleration of tibial reduction (m/s^2) was calculated.

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151 Statistical Analysis

152 All analyses were performed using StatView 5.0 (Abacus Concepts Inc., Berkeley, CA, USA). Shapiro-

153 Wilk test was used to assess normal distribution of each parameter. Mann-Whitney U test was used to
154 compare tibial acceleration between KF injury group and non-KF injury group. Fisher's exact test was
155 used to compare the manual grading of the pivot-shift test between the two groups. Statistical significance
156 was set at $p < 0.05$. The mean \pm standard deviation (SD) was reported for the data with normal distribution.
157 The median and interquartile range (IQR) was reported when the data was not normally distributed.

158 Inter-rater reliability of the KF injury diagnosed by MRI was assessed using complete cohorts by two
159 orthopaedic surgeons. The Cohen's κ coefficient for categorical variables was calculated.³⁸ Agreement
160 rate (percentage of all inter-observer comparisons with agreement/disagreement on a parameter) was also
161 reported. κ values were classified as described by Landis and Koch, with values of 0–0.20, slight
162 agreement; 0.21–0.40: fair agreement; 0.41–0.60: moderate agreement; 0.61–0.80: substantial agreement;
163 and 0.80–1.00: excellent agreement.³⁸

164 An a priori power calculation was performed using G*Power 3.1.9.4 (Franz Paul, Kiel, Germany)
165 based on the past studies that used the EMS to quantify the pivot-shift test.⁴⁴ A prior power analysis
166 showed that a total sample size of 84 knees was required to detect a difference in acceleration of the tibia
167 of 0.5 m/s^2 during pivot shift using Mann-Whitney U test (effect size $d = 0.80$) at a power and significance
168 level of 0.80 and 0.05, respectively (**Supplemental Figure 1, 2**). A difference of 0.9 m/s^2 in acceleration
169 was assumed to be clinically significant as previously reported.⁴⁴

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Results

KF was identified in 93.4% (85/91 cases) of the cases. In six cases, KF was not entirely visualized in the MRI. No significant difference was observed in the rate of KF identification between 3.0-T MRI (93.5%, 29/31 cases) and 1.5-T MRI (93.3%, 56/60 cases) (Pearson's chi-squared test, $p = 0.78$). Twenty of 85 patients (23.5%) were diagnosed with KF injury by MRI. Typical images of KF injury are shown in **Figure 3**. In KF injury group ($n = 20$), eleven cases (55%) fulfilled one direct sign and nine cases (45%) fulfilled two indirect signs.

The rate of KF injury was not significantly different between 3.0-T and 1.5-T MRI (24.1% vs 23.2%, $p = 0.92$). In terms of inter-rater reliability of KF injury diagnosis, the agreement rate of the presence of KF injury between two examiners was 92.9% and Cohen's κ coefficient was 0.797, which is considered to be substantial agreement³⁸ (**Table 1**).

Patient demographics of KF injury group ($n = 20$) and non-KF injury group ($n = 65$) are summarized in **Table 2**. There were no significant differences in age, sex, the period from injury to MRI (8.0 ± 14.0 days vs. 8.9 ± 12.1 days, $p = 0.78$), injury pattern (contact or non-contact), medial meniscus injury rate (30.0% vs. 32.3%, $p = 0.85$), lateral meniscus injury rate (35.0% vs. 40.0%, $p = 0.69$), medial collateral ligament injury, lateral collateral ligament injury, and ALL.

No significant difference was observed in tibial acceleration during the pivot-shift test between KF injury group (median 1.2 m/s^2 , IQR: 0.5–2.1) and non-KF injury group (median 1.0 m/s^2 , IQR: 0.6–

189 1.7) ($p = 0.73$, **Figure 4**). In addition, there was no significant difference in manual grading of the pivot-
 190 shift test between the two groups (**Table 3**, $p = 0.06$). No significant difference was also observed in SSD
 191 in anterior tibial translation during the Lachman test between KF injury group (median 4.3 mm, IQR: 0.8–
 192 7.4) and non-KF injury group (median 6.4 mm, IQR: 4.4–9.6, $p = 0.06$).

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195 **Table 1.** Inter-rater agreement on diagnosing Kaplan fibers injury with all subjects

		Examiner 1		
		Kaplan fibers injury +	Kaplan fibers injury –	Total
Examiner 2	Kaplan fibers injury +	16	2	18
	Kaplan fibers injury –	4	63	67
	Total	20	65	85

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202 **Table 2.** Patient demographics and baseline characteristics^a

	KF injury group (n=20)	non-KF injury group (n=65)	p value ^b
Age at time of injury (years)	27.6 ± 12.6 (range, 13–55)	25.0 ± 11.3 (range, 11–59)	0.41
Sex (male / female)	9 / 11	35 / 30	0.49
Period from injury to MRI (days)	8.0 ± 14.0 (range, 1–63)	8.9 ± 12.1 (range, 0–50)	0.78
Period from MRI to surgery (days)	67.3 ± 49.5	69.1 ± 55.7	0.83
Injury pattern (contact / non-contact)	5 / 15	16 / 49	0.97
Medial meniscal injury (yes / no)	6 / 14	21 / 44	0.85
Lateral meniscal injury (yes / no)	7 / 13	26 / 39	0.69
Medial collateral ligament injury (Grade 1/2/3)	4 (20.0%) 3 / 1 / 0	11 (16.9%) 5 / 6 / 0	0.54
Lateral collateral ligament injury (Grade 1/2/3)	1 (5.0%) 1 / 0 / 0	0 (0%) 0 / 0 / 0	0.07
Anterolateral ligament injury	9 (45.0%)	29 (44.6%)	0.98

^aKF, Kaplan fibers. MRI, magnetic resonance imaging.

^bStatistical significance: p < 0.05.

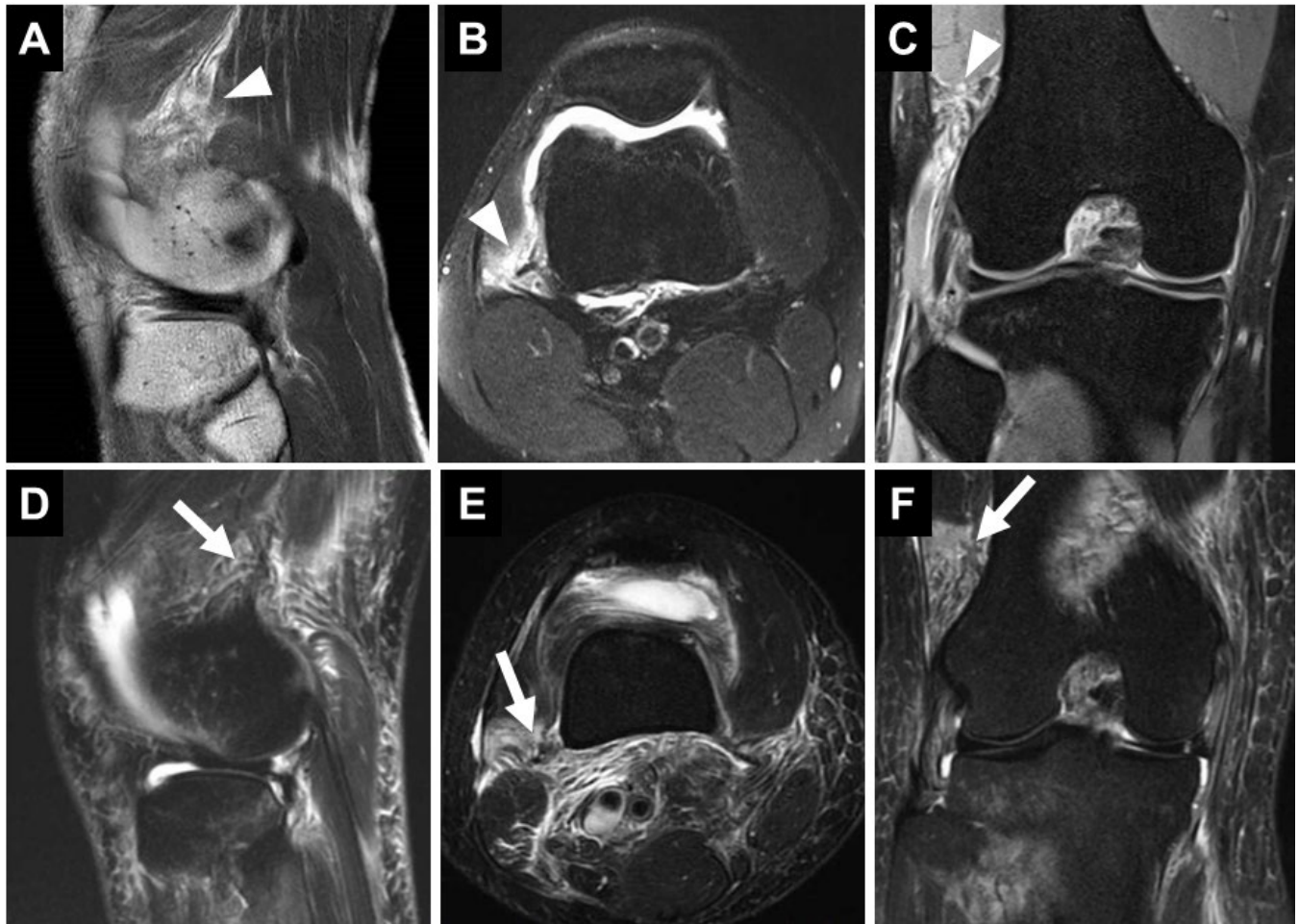


Figure 3. Typical images of KF injury. (A, B, C) There is discontinuity of KF (direct sign, white head). (D, E, F) There is diffuse edema around KF with signal changes and thickening (indirect signs, white arrow).

KF, Kaplan fibers; ACL, anterior cruciate ligament.

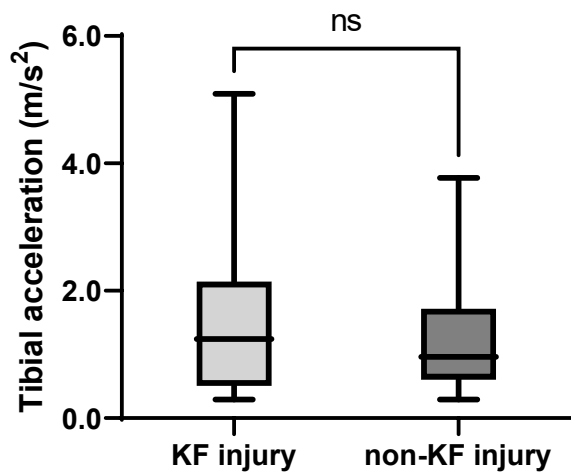


Figure 4. Comparison of tibial acceleration during the pivot-shift test between the KF injury and non-KF injury groups.

There was no significant difference between the groups.

ns, not significant; KF, Kaplan fibers.

Table 3. Manual grading of the pivot-shift test in KF-injury group and non-KF injury group^a

		Kaplan fibers		Total	p value
		Injury group	Non-injury group		
Pivot-shift test	Low grade (0 / 1)	9 (45.0%) (0 / 9)	45 (69.2%) (1 / 44)	54 (63.5%) (1 / 53)	0.06
	High grade (2 / 3)	11 (55.0%) (11 / 0)	20 (30.8%) (18 / 2)	31 (36.5%) (29 / 2)	
Total		20	65	85	

^aKF, Kaplan fibers.

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Discussion

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The main finding of the present study was that concomitant injury to KF did not have a significant impact on anterolateral rotatory laxity measured by quantifying the pivot-shift test using the EMS in the acute ACL-injured knees. This finding is in line with the recent clinical study showing that KF injury was not associated with a higher-grade pivot-shift test, assessed by manual grading.¹³ In addition, there were no differences in the injury patterns or in the existence of the concomitant injuries to collateral ligament, meniscus, and/or ALL between the KF injury group and non-KF injury group. Thus, in the clinical setting, the contribution of KF injury on anterolateral rotatory knee laxity may be limited in ACL injury in contrast to the previous biomechanical studies showing significant contribution of the KF on anterolateral rotatory knee laxity.^{20,36}

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Recently, potential impact of anterolateral complex (ALC) injury on anterolateral rotatory laxity has been extensively discussed in the setting of ACL injury.^{4,5,12,16,22,25,26,35} The ALC consensus group meeting stated that the ALC consists of the superficial and deep aspects of the ITB with its KF attachments on the distal femur, along with the ALL, a capsular structure within the anterolateral capsule.²¹ In 1958, Kaplan³⁴ originally described the layers and attachments of the ITB to the femur. In 1976, Hughston et al.³² described “lateral capsular ligament”, and in 1986, Terry et al.⁴⁹ classified the ITB into the aponeurotic layer, the superficial layer, the middle layer, the deep layer and the capsule-osseous layer, and the KF has

237 shown to be included in the deep layer. In 1993, they also reported that the injury to the capsule-osseous
238 layer of the ITB in ACL-deficient knees was significantly correlated with the grading of the pivot-shift
239 test.⁵⁰ Descriptions of the ALC anatomy are confused by overlapping nomenclature.²¹ Vieira et al.⁵² are
240 often attributed to being the first to describe the ALL, although this was the same name that Terry et al.
241 used to describe the capsule-osseous layer of the ITB.

242 One biomechanical study has shown that the deep and capsule-osseous layer of the ITB, which
243 includes KF, contributed to the restraint of internal rotation in ACL-deficient knees at all range of motion
244 (0°, 30°, 60°, 90°), and internal rotation in simulated pivot-shift test.³⁶ A different biomechanical study has
245 shown that in ACL-deficient knees, the contribution of KF to internal rotation was greater than ALL,
246 particularly at knee flexion deeper than 60°. ²⁰ However, the present clinical study did not show significant
247 influence of KF injury on anterolateral rotatory knee laxity contrary to the hypothesis. One recent clinical
248 study also showed that injury to KF did not result in a higher manual grade of the pivot-shift test with 267
249 patients with ACL-injured knees.¹³ In contrast to the study by Devitt et al, the novelty of the present study
250 was that the pivot-shift test was quantitatively evaluated using the EMS; despite precise assessment of the
251 pivot-shift test, no significant differences were observed between KF injury and non-KF injury groups,
252 which supports the previous report.¹³ Moreover, the incidence of ALL injury was not significantly different
253 between two groups, and confounding by ALL injury would be minimal in the present study.

254 Although MRI would be a useful tool in identifying the structure of the ALC, KF injury diagnosed

255 by MRI may not be an indication for additional procedures such as lateral extra-articular tenodesis based
256 on the current findings whereas some have reported inferior outcomes after ACL reconstructions with
257 ALL injury diagnosed with preoperative MRI.^{11,47} A discrepancy between biomechanical study and
258 clinical study could include potential healing of the soft tissue structures in the interval between MRI and
259 physical examination. Moreover, it is worth mentioning that in the biomechanical model of ALC injury
260 including KF injury, an extensive cutting of not only anterolateral capsule and ALL but also the KF
261 attachment of the ITB is performed to create the worst-case scenario of injury, and this might be at least
262 one reason for the discrepancy between biomechanical findings and clinical findings.

263 Regarding the identification of KF on MRI, Batty et al.⁸ reported that intact KF could be identified
264 in 96% of intact ACL knees on the sagittal slice of 3.0-T MRI, which was similar with the identification
265 rate in the present study (93.4%). The rate of the KF injury varies among the previous reports ranging
266 from 17.4% to 53.8% (**Table 4**).^{9,10,13,15,40,45} Importantly, only one study investigated the association
267 between KF injury and anterolateral rotatory knee laxity among these studies. The wide spectrum of the
268 injury rate could be partially attributable to the different diagnosis criteria, different inclusion criteria,
269 and/or different MRI protocol. This is similar to the reports related to ALL injury with the high variability
270 in the identification of normal and injured ALL definition and the respective MRI findings.¹ The injury
271 rate of the ALL has been reported to range from 11 to 88%.^{1,17} It has been described that hemorrhage in
272 the region of the KF can be observed during surgical exploration,^{16,50} but these studies did not explicitly

273 describe the disruption to the continuity of the KF. The present study used rigorous diagnostic criteria
274 described by Batty et al,⁹ in which the presence of soft tissue edema around the KF was only one factor,
275 and it needed to be associated with at least one other direct or indirect sign of injury of the KF. Devitt et
276 al.¹³ emphasized that it is crucial not to assume that the presence of hemorrhage or edema alone on MRI
277 heralds serious structural damage to the ALC of the knee. In terms of magnetic strength of MRI, no
278 significant difference was observed in the identification rate of KF or the rate of KF injury between 1.5-T
279 and 3.0-T MRI in the present study, suggesting that diagnosis of injury to KF is feasible with 1.5-T MRI.

280 There are several limitations in the present study. Firstly, the MRI scans in the present study were
281 from various sources with differing protocols. However, we believe that this scenario does reflect the
282 current realities for orthopaedic surgeons evaluating MRI scans in the day by day clinical practice.
283 Secondly, the bony morphology, which might have affected the results of pivot-shift (i.e. posterior tibial
284 slope), was not assessed and compared in the present study. Thirdly, the pivot-shift tests were performed
285 by four surgeons. However, it was performed by experienced surgeons in a standardized technique, which
286 reduced inter-examiner variability.²⁸ Thus, inter-examiner variability would have been minimized. Fourth,
287 KF injury may have healed in some cases during the period between the MRI and clinical evaluations
288 under anesthesia, which may have affected the results of the pivot-shift test. However, no significant
289 correlations were found between the period from MRI to surgery and tibial acceleration during the pivot-
290 shift test (single linear regression analysis, $R = 0.11$, $p = 0.30$), suggesting the influence of period from

291 MRI to surgery would be minimal. Moreover, healing potential of the KF is still unknown as the recent
292 study has shown that the ALL has limited intrinsic healing potential.⁴⁶ Fifth, there is inherent bias from
293 the retrospective nature of the methodological design in the present study. Lastly, a post hoc power analysis
294 of Fisher's exact test showed that actual power was 0.52, which suggested the analysis of the manual
295 grading of the pivot-shift test was underpowered, although the present comparison of tibial acceleration
296 between two groups had sufficient power (**Supplemental Figure 2**).

297 The strength of the present study is that anterolateral rotatory knee laxity was quantitatively evaluated
298 by using EMS during the pivot-shift test, and compared between KF injury and non-KF injury groups.
299 The present findings showed that no significant effect of the KF injury on anterolateral rotatory knee laxity
300 was observed in the clinical setting.

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309 **Table 4.** Comparison between the present study and the previous studies in terms of Injury rate of KF in
 310 ACL tears^a

Lead author	MRI	Period from injury to MRI	KF injury rate
Van Dyck P ¹⁵	3.0-T	< 6 weeks	33%
Batty LM ⁹	3.0-T	< 90 days	23.7%
Marom N ⁴⁰	3.0 or 1.5-T	< 6 weeks	Proximal KF: 50-58% Distal KF: 46-60%
Devitt BM ¹³	3.0 or 1.5-T	< 60 days	17.6%
Runer A ⁴⁵	3.0-T	Not reported	21.3%
Berthold DP ¹⁰	3.0 or 1.5-T	< 3 months	35.6-53.8%
The present study	3.0 or 1.5-T	< 90 days	22.0%

^aKF, Kaplan fibers. ACL, anterior cruciate ligament. MRI, magnetic resonance imaging.

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312

Conclusion

313 The KF injury was detected in 22.0% of acute ACL-injured knees using MRI. Concomitant KF injury did
 314 not significantly affect the pivot-shift phenomenon in acute ACL-injured knees. The findings suggest that
 315 the contribution of KF injury to anterolateral rotatory knee laxity may be limited in the clinical setting.

References

1. Andrade R, Rebelo-Marques A, Bastos R, et al. Identification of normal and injured anterolateral ligaments of the knee: a systematic review of magnetic resonance imaging studies. *Arthroscopy*. 2019;35(5):1594-1613.e1. doi:10.1016/j.arthro.2018.10.120
2. Araki D, Kuroda R, Kubo S, et al. A prospective randomised study of anatomical single-bundle versus double-bundle anterior cruciate ligament reconstruction: quantitative evaluation using an electromagnetic measurement system. *Int Orthop*. 2011;35(3):439-446. doi:10.1007/s00264-010-1110-9
3. Araki D, Kuroda R, Kubo S, et al. The use of an electromagnetic measurement system for anterior tibial displacement during the Lachman test. *Arthroscopy*. 2011;27(6):792-802. doi:10.1016/j.arthro.2011.01.012
4. Araki D, Matsushita T, Hoshino Y, et al. The anterolateral structure of the knee does not affect anterior and dynamic rotatory stability in anterior cruciate ligament injury: quantitative evaluation with the electromagnetic measurement system. *Am J Sports Med*. 2019;47(14):3381-3388. doi:10.1177/0363546519879692
5. Ariel de Lima D, Helito CP, Lacerda de Lima L, de Castro Silva D, Costa Cavalcante ML, Dias Leite JA. Anatomy of the Anterolateral ligament of the knee: a systematic review. *Arthroscopy*. 2019;35(2):670-681. doi:10.1016/j.arthro.2018.09.006

- 334 6. Ariel de Lima D, de Lima LL, de Souza NGR, et al. Clinical outcomes of combined anterior
335 cruciate ligament and anterolateral ligament reconstruction: a systematic review and meta-
336 analysis. *Knee Surg Relat Res.* 2021;33(1):1-14. doi:10.1186/s43019-021-00115-1
- 337 7. Ayeni OR, Chahal M, Tran MN, Sprague S. Pivot shift as an outcome measure for ACL
338 reconstruction: a systematic review. *Knee Surg Sports Traumatol Arthrosc.* 2012;20(4):767-777.
339 doi:10.1007/s00167-011-1860-y
- 340 8. Batty L, Murgier J, O’Sullivan R, Webster KE, Feller JA, Devitt BM. The Kaplan fibers of the
341 iliotibial band can be identified on routine knee magnetic resonance imaging. *Am J Sports Med.*
342 2019;47(12):2895-2903. doi:10.1177/0363546519868219
- 343 9. Batty LM, Murgier J, Feller JA, O’Sullivan R, Webster KE, Devitt BM. Radiological
344 identification of injury to the Kaplan fibers of the iliotibial band in association with anterior
345 cruciate ligament injury. *Am J Sports Med.* 2020;48(9):2213-2220.
346 doi:10.1177/0363546520931854
- 347 10. Berthold DP, Willinger L, Muench LN, et al. Visualization of proximal and distal Kaplan fibers
348 using 3-dimensional magnetic resonance imaging and anatomic dissection. *Am J Sports Med.*
349 2020;48(8):1929-1936. doi:10.1177/0363546520919986
- 350 11. Castelli A, Zanon G, Jannelli E, et al. The role of the anterolateral ligament in knee’s
351 biomechanics: a case–control retrospective study. *Eur J Orthop Surg Traumatol.* 2020;30(4):653-

- 352 658. doi:10.1007/s00590-019-02607-z
- 353 12. Claes S, Vereecke E, Maes M, Victor J, Verdonk P, Bellemans J. Anatomy of the anterolateral
354 ligament of the knee. *J Anat.* 2013;223(4):321-328. doi:10.1111/joa.12087
- 355 13. Devitt BM, Al'khafaji I, Blucher N, et al. Association between radiological evidence of Kaplan
356 fiber injury, intraoperative findings, and pivot-shift grade in the setting of acute anterior cruciate
357 ligament injury. *Am J Sports Med.* 2021;49(5):1262-1269. doi:10.1177/0363546521994467
- 358 14. Van Dyck P, Clockaerts S, Vanhoenacker FM, et al. Anterolateral ligament abnormalities in
359 patients with acute anterior cruciate ligament rupture are associated with lateral meniscal and
360 osseous injuries. *Eur Radiol.* 2016;26(10):3383-3391. doi:10.1007/s00330-015-4171-8
- 361 15. Van Dyck P, De Smet E, Roelant E, Parizel PM, Heusdens CHW. Assessment of anterolateral
362 complex injuries by magnetic resonance imaging in patients with acute rupture of the anterior
363 cruciate ligament. *Arthroscopy.* 2019;35(2):521-527. doi:10.1016/j.arthro.2018.08.032
- 364 16. Ferretti A, Fabbri M, Maestri B, Carli A De. Prevalence and classification of injuries of
365 anterolateral complex in acute anterior cruciate ligament tears. *Arthroscopy.* 2017;33(1):147-154.
366 doi:10.1016/j.arthro.2016.05.010
- 367 17. Ferretti A, Monaco E, Redler A, et al. High prevalence of anterolateral ligament abnormalities on
368 mri in knees with acute anterior cruciate ligament injuries: a case-control series from the SANTI
369 Study Group. *Orthop J Sports Med.* 2019;7(6):1-7. doi:10.1177/2325967119852916

- 370 18. Fu FH, Herbst E. Editorial Commentary: The pivot-shift phenomenon is multifactorial.
371 *Arthroscopy*. 2016;32(6):1063-1064. doi:10.1016/j.arthro.2016.03.100
- 372 19. Galway R. Pivot shift: A clinical sign of symptomatic anterior cruciate insufficiency. *J Bone Joint*
373 *Surg Br*. 1972;(54):763-764.
- 374 20. Geeslin AG, Chahla J, Moatshe G, et al. Anterolateral Knee Extra-articular Stabilizers: A robotic
375 sectioning study of the anterolateral ligament and distal iliotibial band Kaplan fibers. *Am J Sports*
376 *Med*. 2018;46(6):1352-1361. doi:10.1177/0363546518759053
- 377 21. Getgood A, Brown C, Lording T, et al. The anterolateral complex of the knee: results from the
378 International ALC Consensus Group Meeting. *Knee Surg Sports Traumatol Arthrosc*.
379 2019;27(1):166-176. doi:10.1007/s00167-018-5072-6
- 380 22. Getgood AMJ, Bryant DM, Litchfield R, et al. Lateral extra-articular tenodesis reduces failure of
381 hamstring tendon autograft anterior cruciate ligament reconstruction: 2-year outcomes from the
382 STABILITY Study Randomized Clinical Trial. *Am J Sports Med*. 2020;48(2):285-297.
383 doi:10.1177/0363546519896333
- 384 23. Godin JA, Chahla J, Moatshe G, et al. A comprehensive reanalysis of the distal iliotibial band:
385 quantitative anatomy, radiographic markers, and biomechanical properties. *Am J Sports Med*.
386 2017;45(11):2595-2603. doi:10.1177/0363546517707961
- 387 24. Grood ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional

- 388 motions: application to the knee. *J Biomech Eng.* 1983;105(2):136-144. doi:10.1115/1.3138397
- 389 25. Helito CP, Helito PVP, Costa HP, Demange MK, Bordalo-Rodrigues M. Assessment of the
390 anterolateral ligament of the knee by magnetic resonance imaging in acute injuries of the anterior
391 cruciate ligament. *Arthroscopy.* 2017;33(1):140-146. doi:10.1016/j.arthro.2016.05.009
- 392 26. Herbst E, Albers M, Burnham JM, et al. The anterolateral complex of the knee: a pictorial essay.
393 *Knee Surg Sports Traumatol Arthrosc.* 2017;25(4):1009-1014. doi:10.1007/s00167-017-4449-2
- 394 27. Herbst E, Albers M, Burnham JM, Fu FH, Musahl V. The anterolateral complex of the knee.
395 *Orthop J Sports Med.* 2017;5(10):1-7. doi:10.1177/2325967117730805
- 396 28. Hoshino Y, Araujo P, Ahlden M, et al. Standardized pivot shift test improves measurement
397 accuracy. *Knee Surg Sports Traumatol Arthrosc.* 2012;20(4):732-736. doi:10.1007/s00167-011-
398 1850-0
- 399 29. Hoshino Y, Araujo P, Ahldén M, et al. Quantitative evaluation of the pivot shift by image
400 analysis using the iPad. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(4):975-980.
401 doi:10.1007/s00167-013-2396-0
- 402 30. Hoshino Y, Hiroshima Y, Miyaji N, et al. Unrepaired lateral meniscus tears lead to remaining
403 pivot-shift in ACL-reconstructed knees. *Knee Surg Sports Traumatol Arthrosc.*
404 2020;28(11):3504-3510. doi:10.1007/s00167-020-06007-3
- 405 31. Hoshino Y, Kuroda R, Nagamune K, et al. In vivo measurement of the pivot-shift test in the

- 406 anterior cruciate ligament-deficient knee using an electromagnetic device. *Am J Sports Med.*
407 2007;35(7):1098-1104. doi:10.1177/0363546507299447
- 408 32. Hughston JC, Andrews JR, Cross MJ, Moschi A. Classification of knee ligament instabilities. Part
409 II. The lateral compartment. *J Bone Joint Surg Am.* 1976;58(2):173-179. doi:10.2106/00004623-
410 197658020-00002
- 411 33. Irrgang JJ, Ho H, Harner CD, Fu FH. Use of the International Knee Documentation Committee
412 Guidelines to assess outcome following anterior cruciate ligament reconstruction. *Knee Surg*
413 *Sports Traumatol Arthrosc.* 1998;6(2):107-114. doi:10.1007/s001670050082
- 414 34. Kaplan EB. The iliotibial tract; clinical and morphological significance. *J Bone Joint Surg Am.*
415 1958;40 A(4):817-832. doi:10.2106/00004623-195840040-00006
- 416 35. Katakura M, Koga H, Nakamura T. Biomechanical effects of additional anterolateral structure
417 reconstruction with different femoral attachment sites on anterior cruciate ligament
418 reconstruction. *Am J Sports Med.* 2019;47(14):3373-3380. doi:10.1177/0363546519880192
- 419 36. Kittl C, El-Daou H, Athwal KK, et al. The Role of the anterolateral structures and the ACL in
420 controlling laxity of the intact and ACL-deficient knee. *Am J Sports Med.* 2016;44(2):345-354.
421 doi:10.1177/0363546515614312
- 422 37. Kraeutler MJ, Welton KL, Chahla J, LaPrade RF, McCarty EC. Current concepts of the
423 anterolateral ligament of the knee: anatomy, biomechanics, and reconstruction. *Am J Sports Med.*

- 424 2018;46(5):1235-1242. doi:10.1177/0363546517701920
- 425 38. Landis JR, Koch GG. The measurement of observer agreement of categorical data. *Biometrics*.
426 1977;33(1):159-174.
- 427 39. Lane CG, Warren R, Pearle AD. The pivot shift. *J Am Acad Orthop Surg*. 2008;16(12):679-688.
- 428 40. Marom N, Greditzer HG, Roux M, et al. The incidence of Kaplan fiber injury associated with
429 acute anterior cruciate ligament tear based on magnetic resonance imaging. *Am J Sports Med*.
430 2020;48(13):3194-3199. doi:10.1177/0363546520956302
- 431 41. Musahl V, Getgood A, Neyret P, et al. Contributions of the anterolateral complex and the
432 anterolateral ligament to rotatory knee stability in the setting of ACL Injury: a roundtable
433 discussion. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(4):997-1008. doi:10.1007/s00167-
434 017-4436-7
- 435 42. Musahl V, Griffith C, Irrgang JJ, et al. Validation of quantitative measures of rotatory knee laxity.
436 *Am J Sports Med*. 2016;44(9):2393-2398. doi:10.1177/0363546516650667
- 437 43. Na BR, Kwak WK, Seo HY, Seon JK. Clinical outcomes of anterolateral ligament reconstruction
438 or lateral extra-articular tenodesis combined with primary ACL reconstruction: a systematic
439 review with meta-analysis. *Orthop J Sports Med*. 2021;9(9):1-12.
440 doi:10.1177/23259671211023099
- 441 44. Nagai K, Hoshino Y, Nishizawa Y, et al. Quantitative comparison of the pivot shift test results

- before and after anterior cruciate ligament reconstruction by using the three-dimensional electromagnetic measurement system. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(10):2876-2881. doi:10.1007/s00167-015-3776-4
45. Runer A, Dammerer D, Kranewitter C, et al. Injuries to the anterolateral ligament are observed more frequently compared to lesions to the deep iliotibial tract (Kaplan fibers) in anterior cruciate ligament deficient knees using magnetic resonance imaging. *Knee Surg Sports Traumatol Arthrosc.* 2021;Mar 26:[Epub ahead of print] PMID: 33770221. doi:10.1007/s00167-021-06535-6
46. Saithna A, Helito CP, Vieira TD, Sonnery-Cottet B, Muramatsu K. The anterolateral ligament has limited intrinsic healing potential: a serial, 3-dimensional–magnetic resonance imaging study of anterior cruciate ligament–injured knees from the SANTI Study Group. *Am J Sports Med.* 2021;49(8):2125-2135. doi:10.1177/03635465211013015
47. Sobrado MF, Giglio PN, Bonadio MB, et al. Outcomes after isolated acute anterior cruciate ligament reconstruction are inferior in patients with an associated anterolateral ligament injury. *Am J Sports Med.* 2020;48(13):3177-3182. doi:10.1177/0363546520956266
48. Sonnery-Cottet B, Thaunat M, Freychet B, Pupim BHB, Murphy CG, Claes S. Outcome of a combined anterior cruciate ligament and anterolateral ligament reconstruction technique with a minimum 2-year follow-up. *Am J Sports Med.* 2015;43(7):1598-1605. doi:10.1177/0363546515571571

- 460 49. Terry GC, Hughston JC, Norwood LA. The anatomy of the iliopatellar band and iliotibial tract.
461 *Am J Sports Med.* 1986;14(1):39-45. doi:10.1177/036354658601400108
- 462 50. Terry GC, Norwood LA, Hughston JC, Caldwell KM. How iliotibial tract injuries of the knee
463 combine with acute anterior cruciate ligament tears to influence abnormal anterior tibial
464 displacement. *Am J Sports Med.* 1993;21(1):55-60. doi:10.1177/036354659302100110
- 465 51. Thein R, Boorman-Padgett J, Stone K, Wickiewicz TL, Imhauser CW, Pearle AD. Biomechanical
466 assessment of the anterolateral ligament of the knee. *J Bone Joint Surg.* 2016;98(11):937-943.
467 doi:10.2106/jbjs.15.00344
- 468 52. Vieira EL, Vieira EÁ, Teixeira da Silva R, dos Santos Berlfein PA, Abdalla RJ, Cohen M. An
469 Anatomic study of the iliotibial tract. *Arthroscopy.* 2007;23(3):269-274.
470 doi:10.1016/j.arthro.2006.11.019

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