Injuries to both anterolateral ligament and Kaplan fiber of the iliotibial band do not increase preoperative pivot-shift phenomenon in ACL injury

Tokura, Takeo ; Nagai, Kanto ; Hoshino, Yuichi ; Watanabe, Shu ; Kanzaki, Noriyuki ; Nishida, Kyohei ; Matsushita, Takehiko ; Kuroda,…

(Citation)
Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology,36:40-44

(Issue Date)
2024-04

(Resource Type)
journal article

(Version)
Version of Record

Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology 36 (2024) 40–44

Contents lists available at ScienceDirect

Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology

journal homepage: www.ap-smart.com

Original article

Injuries to both anterolateral ligament and Kaplan fiber of the iliotibial band do not increase preoperative pivot-shift phenomenon in ACL injury

Takeo Tokura, Kanto Nagai [*], Yuichi Hoshino, Shu Watanabe, Noriyuki Kanzaki, Kyohei Nishida, Takehiko Matsushita, Ryosuke Kuroda

Department of Orthopaedic Surgery, Kobe University Graduate School of Medicine, 7-5-1 Kusunoki-cho, Chuo-ku, Kobe, Hyogo, 650-0017, Japan

A R T I C L E I N F O

Keywords:
Anterior cruciate ligament
Anterolateral complex
Anterolateral ligament
Anterolateral rotatory instability
Kaplan fibers
Pivot-shift test

A B S T R A C T

Background: To assess the incidence of anterolateral ligament (ALL) and Kaplan fiber of the iliotibial band (KF) injuries in patients with acute anterior cruciate ligament (ACL) injury on magnetic resonance imaging (MRI), and to investigate the association between these injuries and the magnitude of preoperative pivot-shift test.

Method: One-hundred and five patients with primary ACL injury were retrospectively reviewed. ALL injury and KF injury were assessed by preoperative MRI, and subjects were allocated into four groups: Group A, neither injury; Group B, only ALL injury; Group C, only KF injury; Group D, simultaneous ALL and KF injuries. Before ACL reconstruction, tibial acceleration during the pivot-shift test was measured by an electromagnetic measurement system, and manual grading was recorded according to the International Knee Documentation Committee (IKDC) guideline.

Results: In MRI, the ALL was identified in 104 patients (99.1%) and KF in 99 patients (94.3%). ALL and KF injuries were observed in 43 patients (43.9%) and 23 patients (23.5%), respectively. Patient distribution to each group was as follows; Group A: 43 patients (43.9%), Group B: 32 patients (32.7%), Group C: 12 patients (12.2%), Group D: 11 patients (11.2%). No significant differences were observed in tibial acceleration, and manual grading among the four groups.

Conclusion: Simultaneous injury to both ALL and KF was uncommon, and preoperative pivot-shift phenomenon did not increase even in those patients. The finding suggests that the role of ALL and KF in controlling anterolateral rotatory knee laxity may be less evident in the clinical setting compared to a biomechanical test setting.

1. Introduction

Eliminating anterolateral rotatory instability (ALRI) is one of the key objectives of anterior cruciate ligament (ACL) reconstruction.[1] There are many factors that affect preoperative ALRI in ACL-deficient knee, including injury to secondary restraint.[2]

In terms of secondary restraint contributing to anterolateral stability of the knee, there has been an increased interest in the anterolateral complex (ALC) of the knee, including mid-third capsular ligament or capsulo-osseous layer of ITB, so called “anterolateral ligament (ALL)” and Kaplan fiber of iliotibial band (KF).[3,4]

The incidence of ALL and KF injury in ACL-injured knee has been shown to be 10.7–78.7%[5–9] and 17.4–71%,[9–13] respectively based on MRI evaluation in previous studies. Although one study has investigated the incidence of simultaneous injury of ALL and KF in ACL-injured knees,[9] rest of the studies investigate solely on ALL or KF. Therefore, there are paucity of data on injury rate of both ALL and KF in ACL-injured knees.

Although there are several studies, including biomechanical and clinical researches, investigating the role of ALL and KF in ALRI in ACL-injured knees, it has not reached its consensus.[11,14–16] Moreover, no one to date has focused on combined injury of ALL and KF, and its impact on ALRI.

In the clinical setting, the pivot-shift test is a valuable manual examination to evaluate ALRI, and its grade correlates with functional outcomes after ACL reconstruction.[17] Recently, there are several validated quantitative evaluation systems to objectify the pivot-shift test,[18,19] and among those, electromagnetic measurement system (EMS), which can measure the acceleration of the tibial posterior reduction (m/s^2), has been shown to have high diagnostic accuracy for the pivot-shift test.[20]

The purposes of the present study were to investigate the incidence

* Corresponding author.
E-mail address: nagaik@med.kobe-u.ac.jp (K. Nagai).

https://doi.org/10.1016/j.asmart.2024.03.004
Received 6 November 2023; Accepted 18 March 2024
Available online 1 April 2024

of both ALL and KF injury using preoperative MRI in ACL-injured knees, and to investigate its association with preoperative pivot-shift test. It was hypothesized that the ACL-injured knees with simultaneous injuries to ALL and KF would have greater tibial acceleration and have higher grade of manual pivot-shift test compared to those without concomitant injury to ALL and KF.

2. Materials and methods

2.1. Subjects

Retrospective cohort study was conducted on series of consecutive patients from March 2013 to July 2021 who suffered from unilateral ACL tear and underwent primary ACL reconstruction in one institution. The diagnoses of ACL tears were made based on clinical examinations and MRI findings, and eventually confirmed arthroscopically during the surgery. The inclusion criteria were as follow: unilateral acute primary ACL tears; time from injury to MRI shorter than 90 days[10]; preoperative evaluation using the EMS. The exclusion criteria were as follow: multi-ligament or realignment procedures; contralateral knee injury; previous injury or surgery on ipsilateral knee; MRI quality less than 1.5-T; insufficient data of the EMS measurement. Originally, 204 patients were detected from the medical records. Of these patients, 105 (52 males and 53 females, mean age: 25.1 ± 11.6 years) fulfilled the criteria and were retrospectively reviewed in the present study. The study was approved by the Institutional Review Board of the authors' affiliated institutions.

2.2. Patient demographics

Demographic data included age, sex, time from injury to MRI, time from injury to surgery. From medical and surgical records, presence of either medial or lateral meniscal injury was also reviewed.

2.3. Radiological analysis

The MRI scans were performed using either 1.5 T or 3.0 T magnets with patients in the supine position and legs extended. Three-plane sequences (sagittal, coronal and axial) using both proton-density-weighted images and fat-suppressed proton-density-weighted images were obtained in each patient. The diagnoses of ALL injuries were made according to the methods reported by Van Dyck et al.[21] The diagnoses of KF injuries were done following the methods reported by Batty et al., previously.[10] Typical images of ALL and KF injuries are shown in Figs. 1 and 2. The whole evaluation was done by single examiner blinded to the results of the pivot-shift evaluations.

According to the MRI findings, the patients were allocated into following groups: Group A, without ALL and KF injury; Group B, only ALL injury; Group C, only KF injury; Group D, simultaneous injury of ALL and KF. The quantitative evaluation and the manual grading of the preoperative pivot-shift test were compared among four groups.

2.4. Assessment of the pivot-shift test

Pivot-sift test was performed under general anesthesia in operating room just before the ACL reconstruction surgery. The standardized pivot-shift test was performed by experienced knee surgeons as previously reported. For the quantitative evaluation of pivot-shift test, acceleration of the posterior tibial reduction was measured using the originally developed EMS as previously described (Fig. 3).[7,18,20] Briefly, two electromagnetic sensors were secured on the thigh and the shank with plastic straps. Before the measurements, seven anatomic bony landmarks of the femur and tibia (greater trochanter, medial and lateral epicondyles, the intersection of medial joint line and the medial collateral ligament, fibular head, and medial and lateral malleoli) were digitized with a probe with a sensor to register three-dimensional

Fig. 1. Typical images of ALL injury. Fat-suppressed coronal T2 images of the right knee with ACL injury. There was disruption of the proximal ALL (white arrow). ACL, anterior cruciate ligament; ALL, anterolateral ligament.

positions of the landmarks in relation to the two sensors. Each femoral and tibial coordinate system was then configured based on the report by Suntay et al.[22] The six degree-of-freedom knee kinematics was monitored with a sampling rate of 240 Hz. The acceleration (m/s^2) of posterior tibial reduction during the pivot-shift phenomenon was calculated by the second derivative of anteroposterior translation velocity over time. The accuracy of this system was verified by Hoshino et al., and the mean standard deviation of the three measurements was 0.2 ± 0.1 m/s^2.[14,18,20] Pivot-shift test was conducted five times, and average of three measurements, excluding maximum and minimum values, were used for the data analysis. The manual grade of the pivot-shift was also assessed according to the International Knee Documentation Committee (IKDC) guidelines: none (−); glide (+); clunk (++); gross (+++).[23] The assessment of manual grading was done blinded to the quantitative evaluation results.

2.5. Statistical analysis

All statistical analyses of recorded data were performed using the Excel statistical software package (BellCurve for Excel; Social Survey Research Information Co., Ltd., Tokyo, Japan). The one-way analysis of variance (ANOVA) was used to compare each value of patient demographics and tibial acceleration among four groups. Post hoc analysis was performed using Tukey-Kramer test. Pearson's chi-squared test was used to compare categorical data among four groups. Statistical significance was set at $p < 0.05$. Inter-rater reliability of the ALL and KF injury diagnosed by MRI was assessed using 20 randomly selected subjects by two orthopaedic surgeons. The Cohen's κcoefficient for categorical variables was then calculated.[24] Agreement rate (percentage of all inter-observer comparisons with agreement/disagreement on certain parameter) was also reported. Kvalues were classified as described by Landis and Koch, with values of 0–0.20, slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; 0.80–1.00, excellent agreement.[24] The results of each data were expressed in mean ± SD, unless otherwise described. A priori power analysis performed by G*Power 3.1.9.4 (Franz Paul, Kiel, Germany) showed that at least 73 subjects were required to compare the

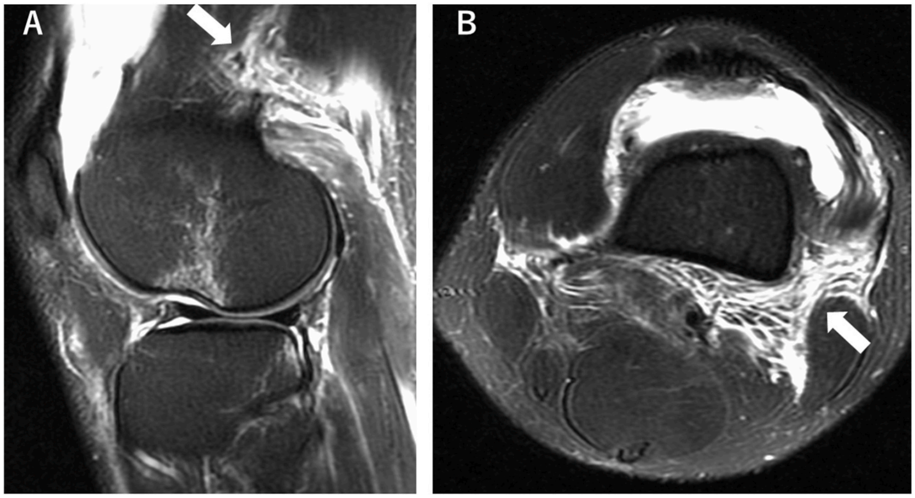

Fig. 2. Typical images of KF injury. (A) Fat-suppressed sagittal, and (B) axial T2 images of the left knee with ACL injury. There was disruption of KF surrounded by diffuse edema. (white arrow). ACL, anterior cruciate ligament; KF, Kaplan fiber.

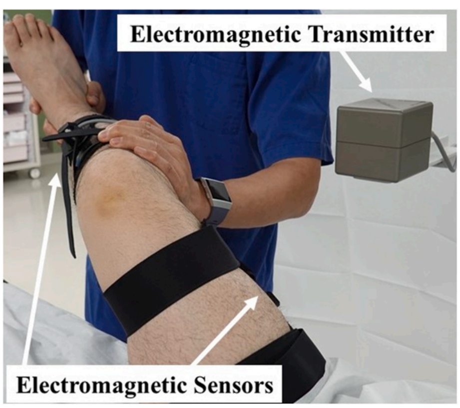

Fig. 3. The electromagnetic measurement system for the pivot-shift test. Two electromagnetic sensors were secured on the thigh and shank with straps. The anatomic coordinates of the knee were set via electromagnetic transmitter. The acceleration of posterior tibial reduction (m/s^2) was calculated.

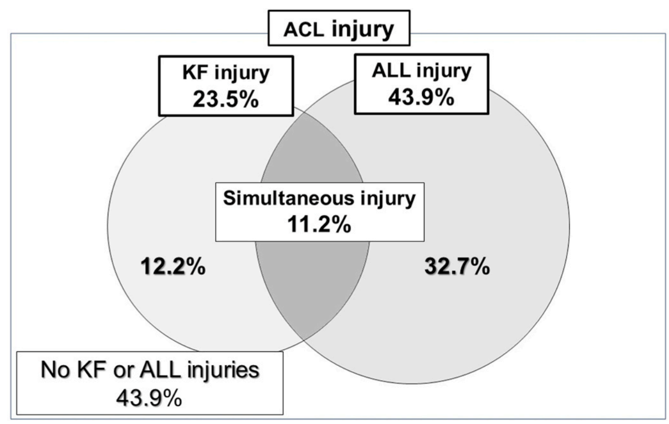

Fig. 4. Diagram of patient distribution of each group.

value among four groups using ANOVA with an effect size of 0.4, a power of 0.8, and an alpha error of 0.05.

3. Results

The ALL and KF were identified in 104 patients (99.0%) and 99 patients (94.3%), respectively. Among 98 patients, in whom both ALL and KF were identified, ALL injuries were observed in 43 patients (43.9%) and KF injuries were observed in 23 patients (23.5%). Patient distribution of each group was as follows: Group A, 43 patients (43.9%); Group B, 32 patients (32.7%); Group C, 12 patients (12.2 %); Group D, 11 patients (11.2%) (Fig. 4). The patient demographics are shown in Table 1.

No significant difference was observed in tibial acceleration during the pivot-shift test among four groups (Fig. 5, 1.4 [95%CI:1.1–1.8] vs. 1.4 [95%CI:1.1–1.7] vs. 1.4 [95%CI:0.9–1.8] vs. 1.7 [95%CI:0.8–2.6], $p = 0.856$). Moreover, there was no significant difference in manual grading of the pivot-shift test among four groups (Table 2, $p = 0.247$).

In terms of inter-rater reliability of ALL and KF injury diagnosis, the agreement rate of the presence of ALL and KF injuries between two examiners were 85% and 90%, and Cohen's κ coefficients were 0.70 and 0.78, respectively, which were both considered to be substantial agreement.[24] (Table 3).

Table 1
Patient demographics and baseline characteristics.

	Group A (n = 43)	Group B (n = 32)	Group C (n = 12)	Group D (n = 11)	p value[a]
Age at the injury, years (range)	21.8[b] (11–59)	29.1 (12–59)	32.5[b] (16–52)	26.5 (13–56)	0.0187*
Sex, male/ female	21/22	16/16	8/4	5/6	0.704
Period from injury to MRI, days	8.8 ± 10.6	8.8 ± 13.0	6.0 ± 6.7	7.5 ± 18.0	0.905
Period from injury to the surgery, days	74.2 ± 54.3	82.0 ± 62.2	70.0 ± 32.7	74.9 ± 63.1	0.913
Total meniscal injury, n (%)	18 (41.9)	20 (62.5)	6 (50.0)	6 (54.5)	0.363
Medial meniscus, n (%)	9 (20.9)	14 (43.8)	3 (25)	4 (36.3)	0.183
Lateral meniscus, n (%)	15 (34.9)	12 (37.5)	5 (41.7)	4 (36.4)	0.978

MRI, magnetic resonance image.
[a] Data reported as mean ± SD unless otherwise indicated. Meniscal injuries were confirmed by arthroscopic inspection during surgery.
[a] Statistical significance: $p < 0.05$.
[b] $p = 0.03$ (group A vs group C).

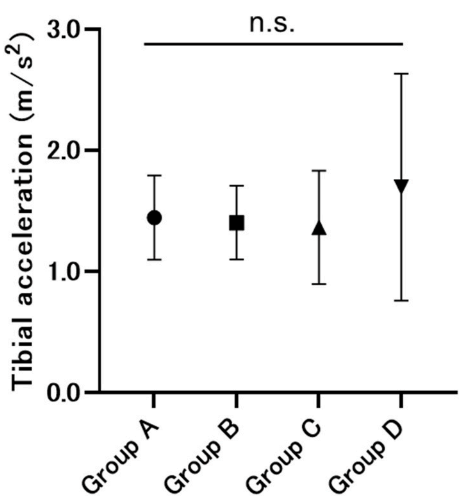

Fig. 5. Comparison of tibial acceleration during the pivot-shift test among four groups. There was no significant difference among four groups. Data are shown as mean ± 95% CI. n.s.: not significant.

Table 2
Manual grading of the pivot-shift tests in four groups.

		Group					
		A	B	C	D	Total	p value
Pivot-shift test	None (−)	1	0	0	1	2	0.247
	Glide (+)	31	17	5	4	57	
	Clunk (++)	10	14	7	6	37	
	Gross (+++)	1	1	0	0	2	
Total		43	32	12	11	98	

Table 3
Results of inter-rater agreement of ALL and KF injury.

		Examiner 1		
		ALL injury +	ALL injury -	Total
Examiner 2	ALL injury +	7	1	8
	ALL injury -	2	10	12
		9	11	20
		Examiner 1		
		Kaplan fiber injury +	Kaplan fiber injury -	Total
Examiner 2	Kaplan fiber injury +	5	2	7
	Kaplan fiber injury -	0	13	13
		5	15	20

ALL, anterolateral ligament.

4. Discussion

The main findings of the present study were (1) more than half of the patients had concomitant injuries to ALL and KF in ACL injury but simultaneous injury to ALL and KF was uncommon (11.2%), and (2) simultaneous injury to both ALL and KF did not have significantly increased preoperative ALRI measured by EMS in the knees with ACL injury. Although many studies have investigated whether injuries to ALL or KF have impact on ALRI, data are contradictory, and it has not reached consensus yet.[11,14,15,25] The finding of present study suggests that the role of ALL and KF in controlling anterolateral rotatory knee laxity may be less evident in clinical setting than biomechanical setting. Although extra-articular procedures, including lateral extra-articular tenodesis (LET) or ALL reconstruction, are recently more often performed because of emerging evidence that it may lower the graft failure rate of ACL reconstruction, clear indications have not been elucidated.[26] According to present study, ALL and KF injuries detected by MRI may not be an absolute indication for adding extra articular procedures to ACL reconstruction.

There are increasing number of studies investigating the association between ALL and ALRI in the setting of ACL injury. However, the results from biomechanical studies are contradictory.[14,15,27] The clinical studies also show conflicting results; Musahl et al. have reported that ALL injury increased the ALRI, evaluated by iPad measurement,[28] while Miyaji et al. showed that ALL injury did not exacerbate the pivot-shift phenomenon, evaluated by both manual grading and EMS, which supports the results of the present study.[7] Similar debate continues on contribution of KF on ALRI as well. There are couple of biomechanical studies reporting that the KF contributed to the restraint of internal rotation in ACL-deficient knee,[25,29] while recent clinical study by Devitt et al. reported that there was no association between radiological evidence of KF injury and manual grade of pivot-shift test,[12] which coincides with the present study.

The present study demonstrated that simultaneous injury of ALL and KF (Group D), which considered the worst scenario of the ALC injury, did not have significant impact on ALRI, which did not support the hypothesis. Discrepancy among the results of each biomechanical study may be due to different procedure of sectioning each structure and different modality of assessing the magnitude of ALRI. Difference between the results of biomechanical and clinical studies may come from potential healing of the soft tissue structures in the interval between MRI and surgery. Moreover, sharp incision of anterolateral complex in biomechanical studies may not simulate the injury pattern in clinical setting, which is thought to be rather stretching-type injury.[8] This could be another reason for such a discrepancy. Recently, there are increasing number of studies investigating the potential of additional extra-articular procedures, such as LET and ALL reconstruction, to ACL reconstruction, and proven its superiority over isolated ACL reconstruction.[26] Although MRI is useful modality to evaluate anterolateral complex injuries, diagnoses made by MRI may not be main reason to perform additional procedures mentioned above.

The strength of the present study was to investigate the detailed rate of ALC injuries, including KF and ALL, using MRI in ACL-deficient knees. Regarding the identification of ALL and KF in ACL-injured knees by MRI, an increased but heterogeneous body of evidence has emerged lately with identification rates ranging between 51% and 100% for ALL and 60.6%–100% for KF. In terms of injury rate, it also ranges from 10.7% to 78.7% for ALL and 17.4%–71% for KF.[5,9,10,13] In the present study, ALL and KF were identified in 99% and 94.3%, respectively and injury rates were 43.9% and 23.5%, respectively, which all coincide with previous reports. Among many reports about MRI evaluation of anterolateral complex, only a few of them have evaluated both ALL and KF in the same patients.[9,12] The wide variance of the identification and injury rate could be partially attributable to the different MRI devices and parameters, different inclusion criteria, and different examination protocols. In the present study, proton-density-weighted images and fat-suppressed proton-density-weighted image of three planes (axial, coronal, and sagittal) were used for evaluation. The examination protocol reported by Van Dyck et al. was utilized for ALL and protocol by Batty for KF evaluation, since acceptable inter-rater correlations were already confirmed by previous studies.[10,21] It might be necessary to standardize the examination protocols to further clarify the clinical importance of ALL and KF injury detected in MRI.

There are several limitations in the present study. Firstly, the present study is a retrospective analysis of prospectively collected data, thus there is possible bias from the retrospective nature of these methodological designs. Secondly, the MRI images in the present study were obtained in different institution with different protocols. However, we excluded poor MRI images, using magnets less than 1.5T, and could obtain high detection rate in both ALL and KF, we believe that reliable and quality data were obtained. Thirdly, the pivot-shift tests were performed by different surgeons, so it may have affected the clinical assessment of ALRI. However, it was performed with standardized maneuver by experienced surgeons to minimize inter-examiner variability.[30] Finally, concomitant meniscal injuries may have affected the magnitude of pivot-shift phenomenon. However, the incidence of meniscal injuries was comparable among four groups, so the bias caused by this may be subtle.

5. Conclusion

More than half of the patients had concomitant injury to anterolateral complex including ALL and KF, but simultaneous injury to both ALL and KF was uncommon (11.2%) in ACL injury. Preoperative pivot-shift phenomenon did not increase even in the knees with simultaneous injuries to both ALL and KF. The finding suggests that the role of ALL and KF in controlling anterolateral rotatory knee laxity may be less evident in clinical setting than biomechanical test setting.

Funding

There is no funding source.

Informed consent

Informed consent was obtained from all the participants.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (the Institutional Review Board of Kobe University (ID No. B190055) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Authors' contribution

Kanto Nagai (Ka.N.), Yuichi Hoshino (Y.H.), Noriyuki Kanzaki (N. K.), Kyohei Nishida (Ky.N.), Takehiko Matsushita (T.M.), and Ryosuke Kuroda (R.K.) conceived the study, and Takeo Tokura (T.T.), Ka.N. participated in the design of the study. T.T. and Shu Watanabe (S.W.) conducted the data collection. T.T. and Ka. N. conducted the pertinent statistical tests and analyses. All authors participated in the interpretation of the data. T.T., Ka.N. wrote the manuscript, and all authors performed critical revision of the manuscript for intellectual content. All authors have read and approved the final manuscript.

Declaration of competing interest

All authors declare that they have no conflict of interest.

References

1. Hughston JC, Andrews JR, Cross MJ, Moschi A. Classification of knee ligament instability part II. The lateral compartment. *J Bone Joint Surg Am*. 1976 Mar;58(2): 173–179.
2. Tanaka M, Vyas D, Moloney G, Bedi A, Pearle AD, Musahl V. What does it take to have a high-grade pivot shift? *Knee Surg Sports Traumatol Arthrosc*. 2012 Apr;20(4), 737–472.
3. Getgood A, Brown C, Lording T, et al. The anterolateral complex of the knee: results from the International ALC Consensus Group Meeting. *Knee Surg Sports Traumatol Arthrosc*. 2019 Jan;27(1):166–176.
4. Herbst E, Albers M, Burnham JM, Fu FH, Musahl V. The anterolateral complex of the knee. *Orthop J Sports Med*. 2017 Oct;5(10), 2325967117730805.
5. 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 May;35(5):1594–1613.
6. Helito CP, Helito PVP, Costa HP, Demange MK, Bordalo-Rodrigues M. Assessment of the anterolateral ligament of the knee by magnetic resonance imaging in acute injuries of the anterior cruciate ligament. *Arthroscopy*. 2017 Jan;33(1):140–146.
7. Miyaji N, Hoshino Y, Tanaka T, et al. MRI-determined anterolateral capsule injury did not affect the pivot-shift in anterior cruciate ligament-injured knees. *Knee Surg Sports Traumatol Arthrosc*. 2019 Nov;27(11):3426–3431.
8. Musahl V, Rahnemai-Azar AA, Costello J, et al. The influence of meniscal and anterolateral capsular injury on knee laxity in patients with anterior cruciate ligament injuries. *Am J Sports Med*. 2016 Dec;44(12):3126–3131.
9. 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 ligamant deficient knees using magnetic resonance imaging. *Knee Surg Sports Traumatol Arthrosc*. 2022 Jan;30(1):309–318.
10. Batty LM, Murgier J, Feller JA, O'Sullivan R, Webster KE, Devitt BM. Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury. *Am J Sports Med*. 2020 Jul;48(9):2213–2220.
11. Devitt BM, Al'khafaji I, Blucher N, et al. Association between radiological evidence of Kaplan fiber injury, intraoperative findings, and pivot-shift grade in the setting of acute anterior cruciate ligament injury. *Am J Sports Med*. 2021 Apr;49(5): 1262–1269.
12. Van Dyck P, De Smet E, Roelant E, Parizel PM, Heusdens CHW. Assessment of anterolateral complex injuries by magnetic resonance imaging in patients with acute rupture of the anterior cruciate ligament. *Arthroscopy*. 2019 Feb;35(2):521–527.
13. Marom N, Greditzer HG 4th, Roux M, et al. The incidence of Kaplan fiber injury associated with acute anterior cruciate ligament tear based on magnetic resonance imaging. *Am J Sports Med*. 2020 Nov;48(13):3194–3199.
14. 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 Dec;47(14), 3381–3188.
15. Kittl C, El-Daou H, Athwal KK, et al. The role of the anterolateral structures and the ACL in controlling laxity of the intact and ACL-deficient knee. *Am J Sports Med*. 2016 Feb;44(2):345–354.
16. Sonnery-Cottet B, Lutz C, Daggett M, et al. The involvement of the anterolateral ligament in rotational control of the knee. *Am J Sports Med*. 2016 May;44(5): 1209–1214.
17. Ayeni OR, Chahal M, Tran MN, Sprague S. Pivot shift as an outcome measure for ACL reconstruction: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2012 Apr;20(4):767–777.
18. Hoshino Y, Kuroda R, Nagamune K, et al. In vivo measurement of the pivot-shift test in the anterior cruciate ligament-deficient knee using an electromagnetic device. *Am J Sports Med*. 2007 Jul;35(7):1098–1104.
19. Tanaka T, Hoshino Y, Miyaji N, et al. The diagnostic reliability of the quantitative pivot-shift evaluation using an electromagnetic measurement system for anterior cruciate ligament deficiency was superior to those of the accelerometer and iPad image analysis. *Knee Surg Sports Traumatol Arthrosc*. 2018 Sep;26(9):2835–2840.
20. 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 Oct;23(10):2876–2881.
21. Van Dyck P, Clockaerts S, Vanhoenacker FM, et al. Anterolateral ligament abnormalities in patients with acute anterior cruciate ligament rupture are associated with lateral meniscal and osseous injuries. *Eur Radiol*. 2016 Oct;26(10): 3383–3391.
22. Grood ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. *J Biomech Eng*. 1983 May;105(2): 136–144.
23. Irrgang JJ, Ho H, Harner CD, Fu FH. Use of the International Knee Documentation Committee guidelines to assess outcome following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 1998;6(2):107–114.
24. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977 Mar;33(1):159–174.
25. Geeslin AG, Chahla J, Moatshe G, et al. Anterolateral knee extra-articular stabilizers: a robotic sectioning study of the anterolateral ligament and distal iliotibial band Kaplan fibers. *Am J Sports Med*. 2018 May;46(6):1352–1361.
26. Getgood AMJ, Bryant DM, Litchfield R, et al. Lateral extra-articular tenodesis reduces failure of hamstring tendon autograft anterior cruciate ligament reconstruction: 2-year outcomes from the STABILITY study randomized clinical trial. *Am J Sports Med*. 2020 Feb;48(2):285–297.
27. Rasmussen MT, Nitri M, Williams BT, et al. An in vitro robotic assessment of the anterolateral ligament, part 1: secondary role of the anterolateral ligament in the setting of an anterior cruciate ligament injury. *Am J Sports Med*. 2016 Mar;44(3): 585–592.
28. Musahl V, Getgood AMJ, Neyret P, et al. Contributions of the anterolateral complex and the anterolateral ligament to rotatory knee stability in the setting of ACL Injury: a roundtable discussion. *Knee Surg Sports Traumatol Arthrosc*. 2017 Apr;25(4): 997–1008.
29. Kopf S, Kauert R, Halfpaap J, Jung T, Becker R. A new quantitative method for pivot shift grading. *Knee Surg Sports Traumatol Arthrosc*. 2012 Apr;20(4):718–723.
30. Hoshino Y, Araujo P, Ahlden M, et al. Standardized pivot shift test improves measurement accuracy. *Knee Surg Sports Traumatol Arthrosc*. 2012 Apr;20(4): 732–736.