The Incidence of Injuries to Ramp Semimembranosus Complex Lesions After ACL Injury

An MRI Study

Julien Druel,*†‡ MD, Christophe Jacquet,†‡ MD, Jean-Charles Escudier,†‡ MD, Chloé Desmaison,†‡ MD, Khakha Raghbir,† MD, Matthieu Ollivier,†‡ MD, PhD, and Daphné Guenoun,†§ MD
Investigation performed at Institute for Locomotion, Aix-Marseille University, Marseille, France

Background: Medial meniscal ramp lesions have recently been an area of interest because of their recognized prevalence in association with anterior cruciate ligament (ACL) ruptures. Anatomically, the medial meniscal ramp is composed of the meniscocapsular ligament in continuity with the semimembranosus muscle and the meniscotibial ligament. Diagnosis of ramp semimembranosus complex (RSC) injuries remains challenging, and their prevalence is likely to be underestimated in comparison with ramp lesions.

Purpose: To determine the prevalence of RSC lesions after a complete ACL rupture.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A retrospective database analysis was performed. The cohort consisted of the first 100 patients with complete ACL rupture confirmed by magnetic resonance imaging (MRI) who underwent knee arthroscopy for ACL reconstruction in 2019. The semimembranosus lesions were identified using MRI by 2 independent radiologists specializing in musculoskeletal imaging. The ramp lesions were initially diagnosed using MRI and then confirmed during arthroscopy by an experienced knee surgeon. The magnitude of rotatory instability was recorded using the pivot-shift test. A multivariate analysis was used to determine the lesions associated with the semimembranosus complex.

Results: Of 100 patients, 53 showed lesions of the RSC; among them, 30 ramp lesions were confirmed after arthroscopic evaluation, and 40 semimembranosus lesions (23 without ramp lesion and 17 with ramp lesion) were found using MRI. A positive pivot shift was present in 57% of patients with combined RSC injury ($P = .04$) compared with 36% in patients without an RSC lesion.

Conclusion: Lesions of the RSC were found in more than half of ACL ruptures in this retrospective cohort. Rotational instability could be associated with combined ACL and RSC injury.

Keywords: knee; ligaments; ACL; knee; meniscus; ramp lesion; semimembranosus; ramp semimembranosus complex; pivot shift

Cavaignac et al[2] recently demonstrated in a cadaveric study that the semimembranosus muscle also has a tendinous branch. It attaches to the posterior horn of the medial meniscus. Anterior cruciate ligament (ACL) ruptures are often associated with injuries to the posteromedial corner (PMC) including a ramp lesion.[12,15] Anatomically, the medial meniscal ramp is composed of the meniscocapsular ligament in continuity with the semimembranosus tendon and the meniscotibial ligament.[14]

Medial meniscal ramp lesions have been an area of interest given their recognized prevalence in association with ACL ruptures.[18] Although the current biomechanical evidence is conflicting,[11] studies have demonstrated an increase in tibial translation and rotation when an ACL rupture is associated with an injury to the posteromedial meniscocapsular junction.[16] There is a direct attachment, or insertion, of

The Orthopaedic Journal of Sports Medicine, 12(9), 23259671241260382
DOI: 10.1177/23259671241260382

the semimembranosus tendon into the periphery of the medial meniscus forming a single entity, the ramp semimembranosus complex[2] (RSC). As such, ramp lesions can be advocated to represent an extension of semimembranosus lesions during trauma to the PMC of the knee. In clinical practice, the prevalence of ramp injuries in the ACL-injured knee can be as high as 30%, with an increased frequency in chronic ACL injuries and ACL revisions.[13] To this day, few studies have investigated the presence of semimembranosus injuries associated with complete ACL rupture.

The objective of this study was to investigate the presence of RSC lesions in association with complete ACL rupture using magnetic resonance imaging (MRI) analysis (for semimembranosus lesions) coupled with arthroscopic diagnosis (for ramp lesions). The secondary objective was to evaluate the predictive factors (including pivot shift, MRI effusion, edema, and meniscal lesion) of semimembranosus lesions in patients with a complete ACL rupture. Our hypothesis was that RSC lesions would be associated with ACL rupture and increased rotatory instability during pivot-shift test. All abbreviations used in this study are listed in Table 1.

TABLE 1
Abbreviations Used in This Study

Abbreviation	Expansion
ACL	Anterior cruciate ligament
CRSCi	Combined ramp semimembranosus complex injury
ICC	Intraclass correlation coefficient
MRI	Magnetic resonance imaging
OR	Odds ratio
PMC	Posteromedial corner
RSC	Ramp semimembranosus complex

METHODS

After local ethics committee approval and general data protection regulation (PADS22-181), the records of patients who underwent primary isolated ACL reconstruction for a complete ACL rupture in our institution between January 2019 and December 2019 were identified in a prospectively collected database. The inclusion criteria included the following: patients experiencing a complete ACL rupture with arthroscopic confirmation, clinical information available, and MRI scans available and performed <3 months after the injury. The exclusion criteria were patients experiencing arthritis, patients requiring multiligament repairs, and patients with a history of ACL reconstruction. The first 100 consecutive participants who fulfilled the inclusion and exclusion criteria were included (Figure 1). The sought-after analysis factors that could quantify the magnitude of injury to the semimembranosus complex were tibial collateral ligament injury, fibular collateral ligament injury, meniscal lesions, bone bruising, joint effusion, and cartilage injuries to the femoral condyles and tibial plateau.

Clinical and Arthroscopic Analysis

All patients underwent careful clinical analysis of their knee including a Lachman test, anterior and posterior drawer test, evaluation of anterolateral rotatory instability with a pivot-shift test, evaluation of laxities of collateral ligaments, and meniscal testing. A contralateral knee evaluation was performed. Rotatory instability was assessed using a pivot-shift test with the patient under general anesthesia and classified into grade 1 to 4[18] subtypes by the senior surgeon (M.O.).

All patients underwent knee arthroscopy by a senior orthopaedic surgeon (M.O.). An assessment of meniscal,

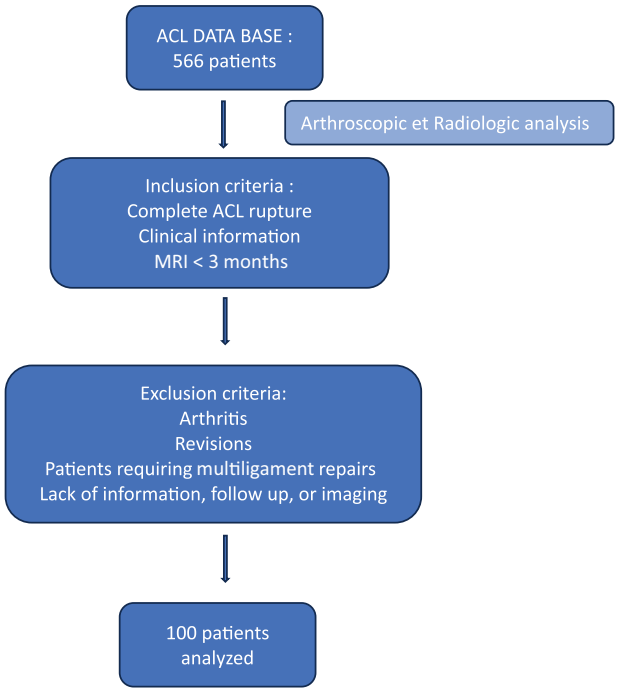

Figure 1. A flowchart illustrating patient enrollment. ACL, anterior cruciate ligament; MRI, magnetic resonance imaging.

*Address correspondence to Julien Druel, MD, APHM, Institute for Locomotion, Sainte-Marguerite Hospital, Department of Orthopaedic Surgery, 6A Boulevard Eugène Pierre, 13005, Marseille, France (email: druel.ortho@gmail.com).
†APHM, Institute for Locomotion, Sainte-Marguerite Hospital, Department of Orthopaedic Surgery, Marseille, France.
‡Aix-Marseille University, CNRS, Marseille, France.
§APHM, Institute for Locomotion, Sainte-Marguerite Hospital, Department of Radiology, Marseille, France.
Final revision submitted January 11, 2024; accepted February 2, 2024.
The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.
Ethical approval for this study was obtained from the Institut Paoli Calmettes (ref No. PADS22-181).

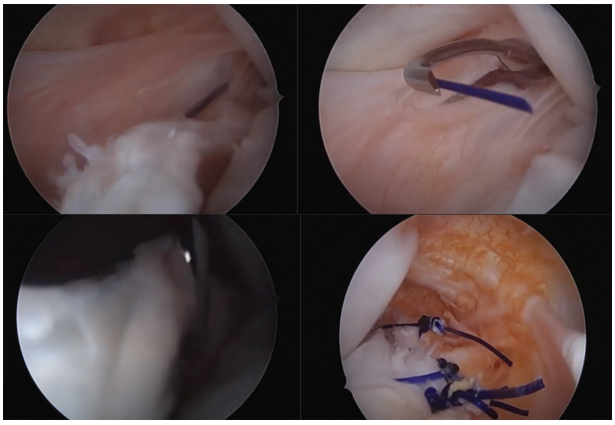

Figure 2. Ramp lesion, posteromedial needle identification, and transnotch arthroscope (top left). Capsulosynovial web (bottom left). Hook suture with Monocryl (top right). Ramp lesion repair with posteromedial suture from the posteromedial portal (bottom right).

cartilage, and ligament injuries was performed. The PMC was systematically explored by transnotch arthroscopy to diagnose posteromedial meniscal lesions. A posteromedial needle test was performed at each arthroscopy to detect ramp lesions (Figure 2).

Radiological Analysis

A first reading of the MRI scans was done by a radiologist (C.D.) as part of the preoperative workup. A second reading of the MRI scans was performed at the time of the study by a radiologist (D.G.) specializing in musculoskeletal imaging. Further analysis of the semimembranosus muscle was performed in the second reading of the images. The first reader was reading prospectively for clinical purposes, and the second reader was participating in a follow-up study. The second reader was not aware of the results of the operative report or the initial imaging report; he had to follow the MRI reading table that was developed as part of the study. One duplicate reading at the 1-month interval of all the MRI scans was done by the second reader.

An MRI reading table was developed as part of the study, searching for ramp lesions of the medial meniscus, lesions of the lateral meniscus, other lesions of the medial meniscus, lesions of the semimembranosus muscle, cartilage lesions, and the presence of bone edema. The results were compared with arthroscopy reports and examination under anesthesia for rotational instability of the knee. Every meniscal lesion identified using MRI was confirmed through arthroscopy. In case of a discrepancy between the operative reports and imaging findings, the gold standard of injury assessment remained the arthroscopic findings.

Radiological analysis of the semimembranosus muscle was classified into 3 subtypes: distal tibial insertion lesion, meniscal insertion lesion, or muscle body lesion (Figure 3).

Figure 3. Magnetic resonance imaging sections with different lesions of the semimembranosus muscle. T2-weighted axial section with capsular lesion of the semimembranosus muscle (left). T2-weighted sagittal section with lesion of the distal insertion of the semimembranosus muscle (right).

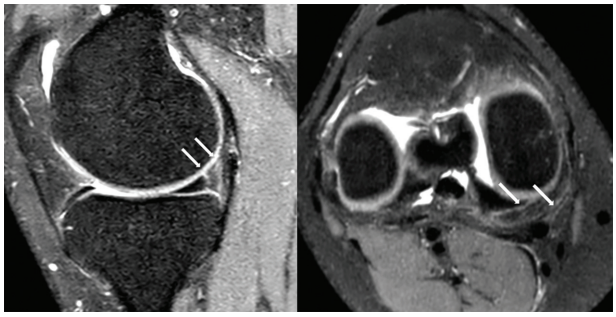

Figure 4. Magnetic resonance imaging sections with a Greif type 5 lesion ramp. T2-weighted sagittal section with ramp lesion (left). T2-weighted axial section with ramp lesion. Arrows represent the peripheral posterior horn meniscal double tear (right and left).

The ramp lesions of the medial meniscus were recorded according to the radiological classification of Greif et al[7] and confirmed by review of the operative report (systematically including posteromedial needle testing) (Figure 4).

Isolated semimembranosus lesions were defined by single semimembranosus lesions that were not associated with ramp lesions. The combined RSC injury (CRSCi) was defined by a simultaneous ramp lesion and semimembranosus lesion.

Statistical Analysis

Descriptive statistics were performed on the 100 included patients to determine counts and the percentage of isolated semimembranosus lesions, ramp lesions, and CRSCi. Means and ranges of weight, height, sex ratio, body mass index, and age at surgery were calculated. Student paired t tests and chi-square tests were planned for intragroup comparisons after Gaussian sample verification. Two-sample t tests and chi-square tests were planned for

TABLE 2
Results of Demographic Parameters[a]

	Minimum	Maximum	Mean
Age at surgery, y	16	63	28.5
Weight, kg	50	118	72.5
Height, cm	162	193	174
BMI, kg/m^2	16.7	38.1	23.9
	No.		Percent
Pivoting sports	80		80
Sex, female/male	34/66		34/66

[a]Pivoting sports were defined as soccer, basketball, tennis, squash, alpine skiing, snowboarding, handball, and gymnastics.

intergroup comparisons. For small subgroup testing of discrete parameters, Fisher exact tests were preferred. Nonparametric tests were used for parameters with non-Gaussian distribution. Multivariate logistic regression was used to determine potential risk and confounding factors associated with semimembranosus complex injury.

The intraclass correlation coefficient (ICC) was used for the reliability analysis for MRI parameters.[1] ICC values of <0.5 were indicative of poor reliability; values between 0.5 and 0.75, moderate reliability; values between 0.75 and 0.9, good reliability; and values of >0.90, excellent reliability.

Statistical significance was assumed at P values of $<.05$. Statistical analysis was performed with SPSS 19.0 (IBM Corp) and RStudio (Windows; Version 1.1.463; posit.co).

RESULTS

All demographic characteristics have been summarized in Table 2.

Of 100 patients, 53 showed RSC lesions; among them, 30 were ramp lesions (suspected by MRI and confirmed arthroscopically) and 40 were semimembranosus lesions (23 without ramp lesions and 17 with ramp lesions). All data are presented in Table 3.

Regarding MRI analysis, intrarater reliability was excellent with an ICC of 1. For interrater reliability, the mean ICC was 0.90, indicating good reliability.

The radiological analysis revealed that effusion (P = .007) and bone edema of the medial tibial plateau (P = .02) were significantly present in the CRSCi. Cartilaginous lesions in the medial and lateral tibial compartments (medial femorotibial joint, P = .01; lateral femorotibial joint, P = .03) were significantly associated with isolated semimembranosus lesions. The clinical analysis of the pivot shift found in 102 knees revealed 23 grade 1, 34 grade 2, 24 grade 3, and 21 grade 4 pivot shift. A positive pivot shift was present in 38% of the isolated semimembranosus lesion group (P = .0008), 35% of the isolated ramp lesion

TABLE 3
Results of 4 Studied Groups[a]

	SM Lesion (n = 23)	Ramp Lesion (n = 30)	CRSCi (n = 17)	No RSC Lesion (n = 30)
Injuries associated with ACL tear	23	30	17	30
Lateral meniscal lesion	21 (.08)	23 (.09)	34 (.02)	20 (.08)
TCL tear	13 (.6)	14 (.35)	22 (.4)	16 (.6)
FCL tear	10 (.5)	14 (.10)	19 (.5)	11 (.5)
Bone bruise	30 (.8)	40 (.006)	55 (.09)	32 (.7)
Bone bruise internal femoral condyle	18 (.9)	27 (.01)	35 (.1)	20 (.8)
Bone bruise external femoral condyle	24 (.3)	34 (.07)	48 (.2)	21 (.4)
Bone bruise external tibial plate	31 (.2)	37 (.009)	52 (.03)	18 (.2)
Bone bruise internal tibial plate	28 (.002)	26 (.2)	40 (.02)	23 (.06)
Joint effusion	36 (.1)	44 (.004)	63 (.007)	50 (.03)
ICRS cartilage lesion, PFJ	7 (.2)	5 (.3)	10 (.4)	0 (.6)
ICRS cartilage lesion, MFTJ	11 (.01)	5 (.5)	13 (.1)	0 (.5)
ICRS cartilage lesion, LFTJ	10 (.03)	3 (.3)	10 (.6)	1 (.5)
Pivot shift				
Grade 1	63	65	43	64
Grade 2	14	18	25	18
Grade 3	12	10	16	12
Grade 4	12	7	16	6

[a]Data are presented as percent or percent (P value). The 4 columns represent the studied groups. The entries represent the variables that were tested for each group. The P value represents the results of the multivariate logistic regression that was used to determine injuries associated with the RSC complex. ACL, anterior cruciate ligament; CRSCi, combined ramp semimembranosus complex injury; FCL, fibular collateral ligament; ICRS, International Cartilage Regeneration & Joint Preservation Society; LFTJ, lateral femorotibial joint; MFTJ, medial femorotibial joint; PFJ, patellofemoral joint; RSC, ramp semimembranosus complex; SM, semimembranosus; TCL, tibial collateral ligament.

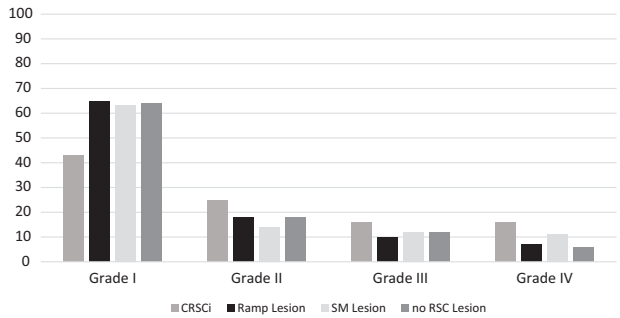

Figure 5. Percentage of pivot shifts by type of lesion (combined ramp semimembranosus complex injury [CRSCi], ramp lesion, semimembranosus [SM] lesion, no ramp semimembranosus complex [RSC] lesion).

group ($P = .007$), and 57% of the CRSCi group ($P = .04$) compared with 36% in patients without RSC lesions (Figure 5).

High-grade pivot shift (grade 4) was found in 10 of 100 patients: 3 patients with isolated semimembranosus injury (odds ratio [OR], 1.5; 95% CI, 0.5-4.3; $P = .5$), 2 with isolated ramp lesion (OR, 1.07; 95% CI, 0.38-3; $P = .5$), 3 with CRSCi (OR, 3; 95% CI, 1.1-8.8; $P = .03$), and 2 with no RSC lesion.

DISCUSSION

The main finding of this study was that RSC lesions are found in more than half of patients experiencing a complete ACL rupture in the present cohort. Medial meniscal ramp lesions and the semimembranosus muscle are likely to form a continuation of a single lesion complex. Their involvement potentially reflects different degrees of severity of a single entity. This study also showed that RSC lesions could be associated with increased rotatory instability of the knee. Further research is needed to clarify rotatory instability mechanisms.

Hughston and Eilers[8] described the close relationship between the posterior horn of the medial meniscus and the semimembranosus muscle. Vieira et al[20] carried out an arthroscopic dissection study of the distal attachment of the semimembranosus muscle, highlighting the complex anatomic relationships with the ramp lesions. They demonstrated that the distal semimembranosus complex is involved in the pathogenesis of ramp lesions. The traction of this complex on the posterior attachment of the medial meniscus leads to posterior translation of the horn and stretching of the meniscocapsular region.[20] These data correspond to the observations of this study because all these structures are anatomically linked to form the RSC.

This study also suggests that RSC lesions were associated with abnormal rotatory tibiofemoral instability. Stephen et al[16] looked at 9 knees and found that rotational and anterior laxities increased significantly after sectioning of the posteromedial meniscocapsular junction in an ACL-deficient knee. In the present study, it was of interest to see that the pivot shift increased in both the ramp injury group and the semimembranosus injury group. It was present in 57% of patients who had lesions involving the CRSCi but also in 38% of isolated injuries of the semimembranosus muscle (Table 3).

Jacquet et al[9] described the persistence of rotational instability at 2 years in a quarter of patients after ACL and lateral extra-articular tenodesis reconstruction associated with meniscal repair. This persistence of the pivot shift could be due to previously undiagnosed lesions, such as semimembranosus lesions. It allows us to better understand the pathophysiology of meniscocapsular and semimembranosus injuries frequently associated with ACL tears. A part of the rotational instability could be due to the damage to the semimembranosus muscle.

One of the strengths of our study is that we used arthroscopy to explore lesions of the RSC. Our study is also one of the only current studies to combine and compare information obtained using arthroscopy and MRI. MRI scans were reviewed by 2 radiologists specializing in musculoskeletal imaging. A comparison with the arthroscopic report was made for each patient. The MRI demonstrated moderate sensitivity but high specificity for the diagnosis of ramp lesions.[10] Routine arthroscopic evaluation is recommended for ramp lesions, whether suspected on MRI or not.[4]

In this study, the 10% decrease in the number of ramp lesions identified on arthroscopy when compared with MRI findings may be explained by the fact that healing of type 1 and 2 lesions took place between imaging and surgery (3 months). The other hypothesis is that these are false-positive results. MRI sensitivity for diagnosis is 0.70.[7,17,18] Analyzing RSC could become an additional diagnostic tool in the search for the capsule-membranous lesions.

Limitations

This study has several limitations. The first is because of the type of study. It is a nonrandomized, retrospective, descriptive study involving only 100 patients. It is limited by its retrospective nature and monocentric population. Second is the time from injury to MRI. Only patients with a time from injury to MRI of <3 months were included; however, we did not distinguish between chronic (>1 months) and acute ACL tears. It would be of interest to know whether the semimembranosus complex injuries are due to the initial trauma or to the chronicity of the biomechanical instability of the knee. Third, the clinical examination of the pivot shift is subjective to the practitioner and therefore may result in selection bias.[19] Fourth, although the intrarater reliability was excellent, the reader used a reading table, which may have affected consistency. Last, we did not statistically differentiate between full and partial tears, which is a selection bias. Partial tears may give diminished results compared with complete lesions.[18]

It is important to emphasize the need to diagnose injuries to the RSC complex that can influence surgical management. Recent articles have recommended repair of

"unstable" ramp lesions. In their study, D'Ambrosi et al[3] demonstrated the difficulty of assessing which ramp lesions require repair. It is not yet clear if, in all cases of ACL reconstruction in which a medial meniscal ramp lesion is encountered, the lesion needs to undergo surgical repair. The presence of CRSCi on preoperative MRI could influence which ramp lesions require repair.

Dold et al[5] explained that patients with multiligament injuries and acute semimembranosus injuries may benefit from direct suture repair of the PMC and that chronic injuries may benefit from reconstruction using the PMC point. Similarly, specific physical therapy can be offered for isolated semimembranosus injuries.[5] Evaluation of the RSC could be an essential step to guide therapeutic management and postoperative rehabilitation. Hamstring rehabilitation might be altered.[6] Further research on the influence of surgical treatments in these lesions would be interesting, including graft choice and use of extra-articular tenodesis.

CONCLUSION

RSC lesions were found in more than half of ACL ruptures in this retrospective cohort. Rotational instability could be associated with combined ACL and RSC injury. RSC assessment using MRI and arthroscopy appears to be essential in the diagnosis and treatment of ACL injury. Further research is needed to clarify the mechanism of injury and individual contributions of RSC lesions.

Better determination of these RSC lesions could lead to a modification of the surgical management and a specific postoperative rehabilitation for semimembranosus injuries.

REFERENCES

1. Benchoufi M, Matzner-Lober E, Molinari N, Jannot AS, Soyer P. Interobserver agreement issues in radiology. *Diagn Interv Imaging*. 2020;101(10):639-641.
2. Cavaignac E, Sylvie R, Teulières M, et al. What is the relationship between the distal semimembranosus tendon and the medial meniscus? A gross and microscopic analysis from the SANTI Study Group. *Am J Sports Med*. 2021;49(2):459-466.
3. D'Ambrosi R, Meena A, Raj A, et al. Good results after treatment of RAMP lesions in association with ACL reconstruction: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2023;31(1):358-371.
4. DePhillipo NN, Cinque ME, Chahla J, Geeslin AG, Engebretsen L, LaPrade RF. Incidence and detection of meniscal ramp lesions on magnetic resonance imaging in patients with anterior cruciate ligament reconstruction. *Am J Sports Med*. 2017;45(10):2233-2237.
5. Dold AP, Swensen S, Strauss E, Alaia M. The posteromedial corner of the knee: anatomy, pathology, and management strategies. *J Am Acad Orthop Surg*. 2017;25(11):752-761.
6. Glattke KE, Tummala SV, Chhabra A. Anterior cruciate ligament reconstruction recovery and rehabilitation: a systematic review. *J Bone Joint Surg Am*. 2022;104(8):739-754.
7. Greif DN, Baraga MG, Rizzo MG, et al. MRI appearance of the different meniscal ramp lesion types, with clinical and arthroscopic correlation. *Skeletal Radiol*. 2020;49(5):677-689.
8. Hughston JC, Eilers AF. The role of the posterior oblique ligament in repairs of acute medial (collateral) ligament tears of the knee. *J Bone Joint Surg Am*. 1973;55(5):923-940.
9. Jacquet C, Pioger C, Seil R, et al. Incidence and risk factors for residual high-grade pivot shift after ACL reconstruction with or without a lateral extra-articular tenodesis. *Orthop J Sports Med*. 2021;9(5):23259671211003590.
10. Koo B, Lee SH, Yun SJ, Song JG. Diagnostic performance of magnetic resonance imaging for detecting meniscal ramp lesions in patients with anterior cruciate ligament tears: a systematic review and meta-analysis. *Am J Sports Med*. 2020;48(8):2051-2059.
11. Naendrup JH, Pfeiffer TR, Chan C, et al. Effect of meniscal ramp lesion repair on knee kinematics, bony contact forces, and in situ forces in the anterior cruciate ligament: response. *Am J Sports Med*. 2020;48(2):NP25-NP27.
12. Seil R, Mouton C, Coquay J, et al. Ramp lesions associated with ACL injuries are more likely to be present in contact injuries and complete ACL tears. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(4):1080-1085.
13. Sonnery-Cottet B. Editorial commentary: Ramp lesion: the eye sees only what the mind is prepared to comprehend. *Arthroscopy*. 2020;36(11):2934-2937.
14. Sonnery-Cottet B, Conteduca J, Thaunat M, Gunepin FX, Seil R. Hidden lesions of the posterior horn of the medial meniscus: a systematic arthroscopic exploration of the concealed portion of the knee. *Am J Sports Med*. 2014;42(4):921-926.
15. Sonnery-Cottet B, Serra Cruz R, Vieira TD, Goes RA, Saithna A. Ramp lesions: an unrecognized posteromedial instability? *Clin Sports Med*. 2020;39(1):69-81.
16. Stephen JM, Halewood C, Kittl C, Bollen SR, Williams A, Amis AA. Posteromedial meniscocapsular lesions increase tibiofemoral joint laxity with anterior cruciate ligament deficiency, and their repair reduces laxity. *Am J Sports Med*. 2016;44(2):400-408.
17. Taneja AK, Miranda FC, Rosemberg LA, Santos DCB. Meniscal ramp lesions: an illustrated review. *Insights Imaging*. 2021;12:134.
18. Thaunat M, Ingale P, Penet A, et al. Ramp lesion subtypes: prevalence, imaging, and arthroscopic findings in 2156 anterior cruciate ligament reconstructions. *Am J Sports Med*. 2021;49(7):1813-1821.
19. Vaudreuil NJ, Rothrauff BB, de Sa D, Musahl V. The pivot shift: current experimental methodology and clinical utility for anterior cruciate ligament rupture and associated injury. *Curr Rev Musculoskelet Med*. 2019;12(1):41-49.
20. Vieira TD, Pioger C, Frank F, et al. Arthroscopic dissection of the distal semimembranosus tendon: an anatomical perspective on posteromedial instability and ramp lesions. *Arthrosc Tech*. 2019;8(9):e987-e991.