Original Article

Steep posterior slope of the medial tibial plateau is associated with ramp lesions of the medial meniscus and a concomitant anterior cruciate ligament injury

Yuki Okazaki [a, b], Takayuki Furumatsu [a, *], Takaaki Hiranaka [a], Keisuke Kintaka [a], Yuya Kodama [a, c], Yusuke Kamatsuki [a], Toshifumi Ozaki [a]

[a] Department of Orthopaedic Surgery, Okayama University Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences, 2-5-1 Shikatacho, Kitaku, Okayama, 700-8558, Japan
[b] Department of Orthopaedic Surgery, Kosei Hospital, 3-8-35 Kosei-cho, Kita-ku, Okayama, 700-0985, Japan
[c] Department of Orthopaedic Surgery, University of Pittsburgh, 4200 Fifth Avenue, Pittsburgh, PA, 15260, USA

ARTICLE INFO

ABSTRACT

Background: Medial meniscus (MM) tears are associated with both acute and chronic anterior cruciate ligament (ACL) insufficiency and can lead to degenerative changes in the knee. ACL reconstruction (ACLR) combined with the meniscal repair was reported to result in decreased anterior knee joint laxity with evidence of improved patient-reported outcomes in the long term. However, a subtle tear of the MM posterior segment, also known as a ramp lesion, is difficult to detect on conventional magnetic resonance imaging (MRI) and is frequently missed in ACL-deficient knees. However, there are few studies about the associations between bone geometry and ramp lesion of the MM. This study aimed to compare sagittal medial tibial slope (MTS), medial tibial plateau depth (MTPD), and coronal tibial slope (CTS) between ACL-injured knees with and without ramp lesion of the MM. We hypothesised that patients with ramp lesion of the MM and a concomitant ACL injury have a steeper MTS and shallower MTPD than those without ramp lesion of the MM.
Methods: Twenty-seven patients who underwent ACLR (group A), and 15 patients with combined MM repair (group AM) were included in the study. Anterior tibial translation (ATT) was measured under general anaesthesia just before surgery using a knee arthrometer. MRI was performed in the 10°-knee-flexed position. The MTS and MTPD were measured on sagittal view, and the CTS was measured on coronal view. These parameters were compared between the groups. Differences in MRI measurements or patient demographics between the groups were evaluated using the Mann-Whitney U test.
Results: No significant difference was observed in demographic data and post-operative side-to-side difference in ATT between both groups. Pre-operative ATT was significantly higher in group AM than in group A ($P < 0.05$), whereas post-operative ATT was similar in both groups. Further, Pre-operative ATT was significantly higher in patients with MTS $\geq 5.0°$ than in those with MTS $< 5.0°$ ($P < 0.05$). In groups A and AM, the MTS were $3.6° \pm 1.8°$ and $6.2° \pm 2.9°$, the MTPD were 2.0 ± 0.5 mm and 2.1 ± 0.6 mm, and the CTS were $2.5° \pm 1.8°$ and $2.4° \pm 1.6°$, respectively. Patients in group AM had a significantly steeper MTS compared to those in group A ($P < 0.01$), whereas MTPD and CTS were nearly the same in both groups. When the MTS cut-off value was set at $5.0°$, the sensitivity and specificity for ACL injury with concomitant ramp lesion of the MM were 0.73 and 0.76, respectively.
Conclusion: A steep posterior slope of the medial tibial plateau is a risk factor for ramp lesion of the MM associated with an ACL injury. Especially in patients with MTS $\geq 5.0°$, an occult MM ramp lesion should be strongly suspected, and surgeons should prepare for MM repair in combination with ACLR.

* Corresponding author.
E-mail address: matino@md.okayama-u.ac.jp (T. Furumatsu).

Introduction

Medial meniscus (MM) tears are associated with chronic anterior cruciate ligament (ACL) insufficiency and can lead to degenerative changes in the knee, depending on the severity of the instability.[1] Peripheral longitudinal tears of the MM are also commonly seen with acute ACL injuries.[2] Because the posterior segment of the MM acts as a secondary stabiliser of anterior tibial translation (ATT)[3,4] and the ACL is the main restriction to anterior tibial loads,[5,6] it is reported that the repair of peripheral MM tears decreases the risk of post-operative knee pain and subsequent arthroscopic salvation in ACL-reconstructed knees.[7,8] In a systematic review, ACL reconstruction (ACLR) combined with the meniscal repair was reported to result in decreased anterior knee joint laxity with evidence of improved patient-reported outcomes in the long term.[9] However, a subtle tear of the MM posterior segment, also known as a ramp lesion, is difficult to detect on conventional magnetic resonance imaging (MRI) and is frequently missed in ACL-deficient knees, even on standard arthroscopy with anterior portals only.[10] It is, however, important to repair this lesion in case of instability.[11]

Bone morphological factors are also important for the menisci, especially in the ACL-deficient knee. To date, studies on the association between tibial geometry or biomechanics and the ACL or bilateral meniscus have been reported.[12–17] The geometry of the proximal tibial plateau has an influence on the biomechanics of the knee joint,[18,19] and an important characteristic of the tibial plateau is its posterior slope.[18,20] Biomechanical studies have shown that a steep medial tibial slope (MTS) leads to increased ATT under load, which may increase the forces acting on the menisci.[18,20–24] Furthermore, a complex MM tear is more frequently associated with a biconcave medial tibial plateau,[25] and a shallower MTS and lateral tibial slope (LTS) may result in impingement of MM posterior horn and lateral meniscus (LM) anterior horn, respectively.[26]

Recently, a comprehensive study reported risk factors for ramp lesions in the ACL-deficient knee, which included bone contusion on the posterior medial tibial plateau, chronic injury, steeper medial tibial and meniscal slope, gradual LTS, and varus knee alignment >3°.[27] However, there are few studies about the associations between bone geometry and ramp lesion of the MM. Therefore, we aimed to study these associations and investigate the unique bone geometry of patients with MM ramp lesion and concomitant ACL injury. We hypothesised that patients with ramp lesion of the MM and a concomitant ACL injury have a steeper MTS and shallower medial tibial plateau depth (MTPD) than those without ramp lesion of the MM.

Materials and methods

A retrospective design was used to compare sagittal MTS, MTPD, and coronal tibial slope (CTS) between patients who underwent ACLR (group A) and those who underwent combined MM repair (group AM). Ramp lesion of the MM was identified through a transnotch view using the standard anterolateral portal[10] according to Thaunat classification.[28] MM repair was performed for an unstable lesion. A stable MM (type 1 ramp lesion) was not repaired, and only ACLR was performed (1 case). A chart review was conducted using our electronic medical record system to identify all patients who underwent ACLR at our institution between January 2013 and March 2019. A total of 87 patients underwent ACLR, and 60 (69%) were females. A significant difference in within-subject MTS values has been reported when females were considered separately.[29] Moreover, a greater MTS is associated with increased ATT in females with ACL-deficient knees compared to males, regardless of meniscus lesions.[30] Therefore, for the purpose of this

study, only women were included for further analysis. Exclusion criteria included patients who had undergone transgender surgery (transforming from female to male), duration from injury to surgery ≥1 year, single-bundle reconstruction including bone-patellar tendon-bone graft, and concomitant injuries such as an LM tear and a history of surgery in the index knee. Eighteen patients were excluded, and the final sample sizes were 27 and 15 in groups A and AM, respectively, which demonstrated adequate power (>0.87) to detect a significant difference in MTS between the groups.

ATT was measured under general anaesthesia just before surgery using a knee arthrometer (KS Measure KSM-100; SIGMAX, Tokyo, Japan). Patient demographics are shown in Table 1.

The study was approved by our institutional review board, and written informed consent was provided by all patients.

MRI measurement

The patients underwent MRI evaluations using an Achieva 1.5 T scanner (Philips, Amsterdam, the Netherlands) or EXCELART Vantage™ powered by Atlas 1.5 T with an integrated coil (Toshiba Medical Systems, Tochigi, Japan). Standard sequences of the Achieva included sagittal (repetition time [TR]/echo time [TE], 601/14) and coronal (TR/TE, 553/14) T2-weighted multi-echo with a 30° flip angle. Standard sequences of the Vantage included sagittal and coronal proton spin-echo (TR/TE, 2300/18) with a 90° flip angle. The slice thickness was 3 mm with a 0.6 mm gap. The field of view was 18 cm, with an acquisition matrix size of 512 × 358. We used a picture archiving and communication system (FUJIFILM Holdings Corporation, Tokyo, Japan) to measure the MTS, MTPD, and CTS according to the method described by Hudek et al.[31] and Hashemi et al.,[29] as described in detail below.

Values were rounded to one decimal place. All measurements were performed by two board-certified orthopaedic surgeons on a best agreement basis. To determine the inter-observer reproducibility, additional measurements were performed independently by two reviewers on 20 randomly selected MRI scans, and interclass correlation coefficients (ICCs) were calculated. Inter-observer and intra-observer reliabilities were assessed using ICC. ICC values > 0.9 were considered excellent, those between 0.8 and 0.9 were considered good, and those <0.8 were considered poor. The inter-observer/intra-observer reliabilities for the measurements were satisfactory with mean ICC values of 0.91/0.93 for MTS, 0.88/0.91 for MTPD, and 0.90/0.92 for CTS.

MTS was measured on sagittal proton density sequences according to the method described by Hudek et al.[31] (Fig. 1), which has been reported to be the most reproducible for measuring sagittal tibial slopes on MRI and is independent of the proximal tibial length.[32] First, the proximal anatomical axis of the tibia was defined on the central sagittal slice in which the attachment of the posterior cruciate ligament and the intercondylar eminence was visualised, and both the anterior and posterior tibial cortices appeared in a concave shape. Within this slice, two circles were drawn in the proximal tibia. The proximal circle was fit within the proximal, anterior, and posterior cortical borders. The distal circle was fit within the anterior and posterior cortices with its centre positioned on the perimeter of the proximal circle. A line drawn through the centres of both circles defined the proximal anatomical axis. Then, the sagittal slice showing the mediolateral centres of the medial plateau was identified. On this image, a tangent to the medial plateau, connecting the uppermost superior-anterior and posterior cortex edges (excluding articular cartilage) was drawn. MTS was defined as the angle from the orthogonal to the proximal anatomical axis and the tangent to the medial plateau. Since no clear definition exists for abnormal LTS,[33] only MTS was measured in the present study.

Table 1
Demographic and clinical characteristics of the patients.

Variable	Group A[a]	Group AM[b]	*P* value
Number of patients	27	15	
Age (years)	27.0 ± 11.6	26.8 ± 12.8	>0.05
Height (m)	1.6 ± 0.04	1.6 ± 0.04	>0.05
Weight (kg)	59.7 ± 10.4	58.8 ± 14.5	>0.05
Body mass index (kg/m^2)	23.7 ± 4.2	23.1 ± 5.8	>0.05
Duration from injury to surgery (weeks)	18.7 ± 12.0	16.6 ± 14.2	>0.05
Pre-operative Tegner activity score	4.4 ± 2.0	4.2 ± 1.4	>0.05
Pre-operative side-to-side difference in ATT	4.5 ± 1.5	6.0 ± 2.1	<0.05*
Post-operative side-to-side difference in ATT	−0.3 ± 1.0	−0.3 ± 1.4	>0.05

Data are presented as mean ± standard deviation.
Significant difference (*$P < 0.05$) was observed using Mann Whitney-*U* test.
ATT, anterior tibial translation.
[a] Group A, group that had anterior cruciate ligament reconstruction only.
[b] Group AM, group that had anterior cruciate ligament reconstruction and medial meniscus repair.

MTPD was measured by drawing a line to connect the superior and inferior crests of the tibial plateau in the same plane in which MTS was measured. Another line parallel to this connecting line was then drawn tangential to the lowest point of the concavity, representing the lowest boundary of the subchondral bone. The perpendicular distance between the two lines was then measured and used to represent MTPD (Fig. 1).

CTS was measured after determining the orientation of the longitudinal axis of the tibia according to the method described by Hashemi et al.[29] This was done by determining the midpoint of the medial-to-lateral width of the tibia at two points located approximately 4—5 cm apart and as distally in the image as possible. The extended line connecting the two midpoints represents the longitudinal (or diaphyseal) axis of the tibia in the coronal plane. Then, CTS was measured as the angle between a line joining the peak points on the medial and lateral aspects of the plateau and the line perpendicular to the longitudinal axis.

Statistical analysis

Data are reported as mean ± standard deviation. Statistical analysis and sample size/power calculation were performed using EZR software (Saitama Medical Center Jichi Medical University, Tochigi, Japan).[34] Differences in MRI measurements or patient demographics between the groups were evaluated using the Mann-Whitney *U* test. Statistical significance was set at $P < 0.05$. Two orthopaedic surgeons independently measured the MTS, MTPD, and CTS twice at 2-week intervals. To determine the number of test samples, the sample size calculation was performed under a significance level of 0.05 and a power of 0.80, and the resulting sample sizes were 24 and 13 in groups A and AM, respectively.

Results

No significant difference was observed in demographic data,
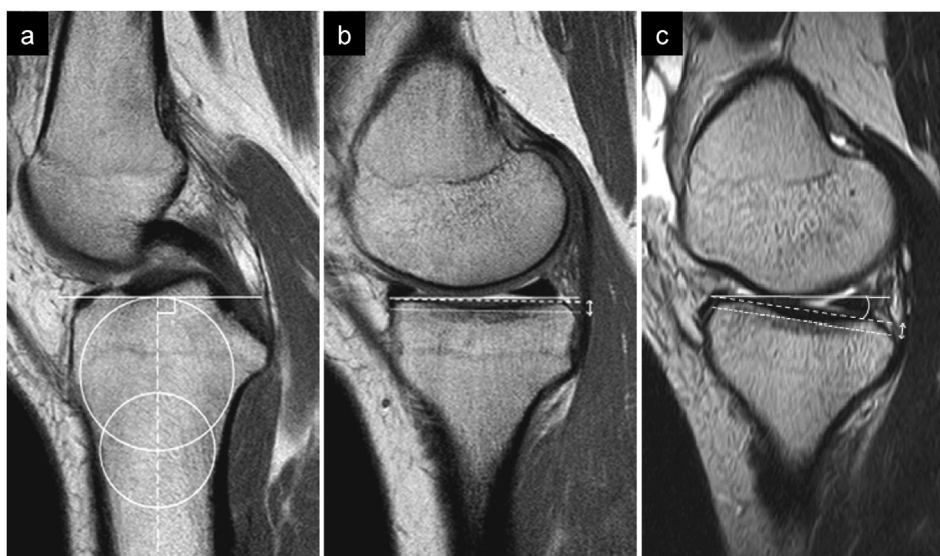

Fig. 1. Magnetic resonance images of a knee with an ACL injury.
(a) Determination of the tibial axis (long-dashed line) according to the method described by Hudek et al.[31] The solid line is perpendicular to the tibial axis.
(b) Measurement of the MTS (1°) in the knee without ramp lesion of the MM. An angle is formed by the solid line perpendicular to the tibial axis and the dashed line connecting the uppermost superior-anterior and posterior cortex edges.
(c) Measurement of the MTS (8°) in the knee with ramp lesion of the MM. An angle is formed by the solid line perpendicular to the tibial axis and the dashed line connecting the uppermost superior-anterior and posterior cortex edges. ACL, anterior cruciate ligament; MM, medial meniscus; MTS, medial tibial slope.

including age, body mass index, duration from injury to surgery, pre-operative Tegner activity score, and post-operative side-to-side difference in ATT (Table 1). Bucket handle tear was not detected in either group.

In group A (Fig. 1 a and b) and group AM (Fig. 1c), the MTS values were 3.6° ± 1.8° and 6.2° ± 2.9°, the MTPD values were 2.0 ± 0.5 mm and 2.1 ± 0.6 mm, and the CTS values were 2.5° ± 1.8° and 2.4° ± 1.6°, respectively. Patients in group AM had a significantly steeper MTS compared to those in group A ($P < 0.01$, power > 0.87), whereas MTPD and CTS were nearly the same in both groups. The sensitivity was 0.73 and the specificity was 0.76 when the MTS cut-off value was set at 5.0° (Fig. 2).

Pre-operative ATT was significantly higher in group AM than in group A ($P < 0.05$), whereas post-operative ATT was similar in both groups (Table 1). Further, Pre-operative ATT was significantly higher in patients with MTS $\geq 5.0°$ than in those with MTS $< 5.0°$ ($P < 0.05$).
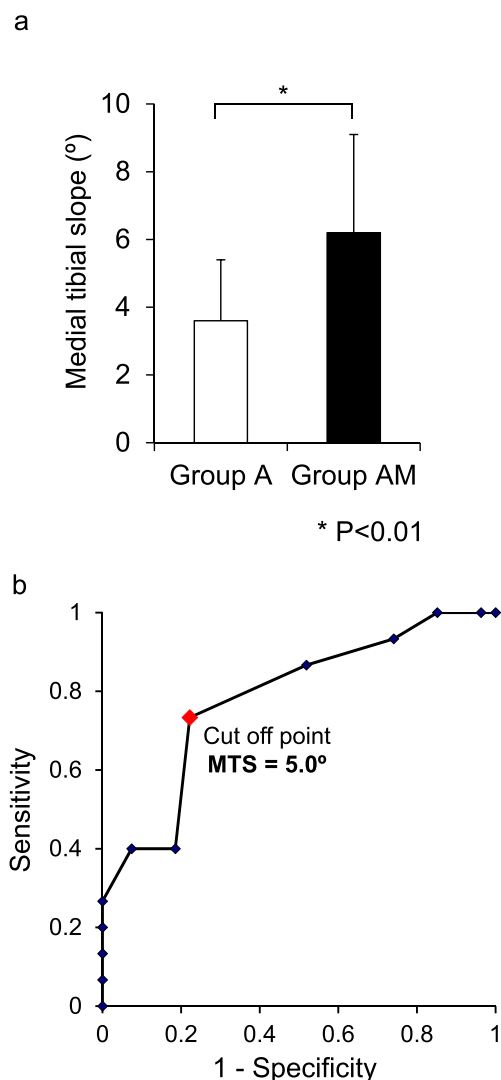

Fig. 2. Magnetic resonance image-based MTS along with ROC curve for MTS. (a) The MTS was significantly steeper in the group with an ACL injury and ramp lesion of the MM (Group AM) than in the group with an ACL injury only (Group A). *$P < 0.01$.
(b) The sensitivity/specificity was 0.73/0.76 when MTS cut-off value was set at 5.0° (red point).
ACL, anterior cruciate ligament; MM, medial meniscus; MTS, medial tibial slope; ROC, receiver operating characteristic.

Discussion

The most important finding of this study is that patients with ramp lesion of the MM and a concomitant ACL injury had a steeper MTS than those without ramp lesion of the MM. Our hypothesis is partially confirmed. Further, relatively high sensitivity/specificity were observed when the cut-off value was set at 5.0°.

MM tears are often reported to be associated with chronic ACL insufficiency and can lead to degenerative change in the knee, depending on the severity of instability.[1] Several authors have also reported that repair of peripheral MM tears decreases the risk of postoperative knee pain and subsequent arthroscopic salvation in ACL-reconstructed knees.[7,8]

In a clinical situation, peripheral longitudinal tears of the MM are commonly seen with acute ACL injuries.[2] The posterior segment of the MM is often deformed and shifted posteriorly in ACL-deficient knees complicated with an MM tear at 90° of knee flexion.[35] Although longitudinal tears of the MM are correlated with MM extrusion[36] and the anteroposterior length and radial extrusion of the MM increase even after ACLR,[37] ACLR can reduce the deformation of the MM posterior segment in the knee-flexed position by reducing abnormal ATT. ACLR also possibly prevents secondary injury to the MM posterior segment and cartilage, which can progress to knee osteoarthritis.[35] Furthermore, in a systematic review, ACLR combined with meniscal repair was reported to result in decreased anterior knee joint laxity with evidence of improved patient-reported outcomes in the long term.[9]

Although favourable clinical outcomes have been reported as above, subtle tears of the MM posterior segment or ramp lesions are difficult to detect on only MRI, and these lesions, which should be repaired in case of instability, are frequently missed in ACL-deficient knees even on standard arthroscopy with anterior portals only.[11]

To date, many studies on bone morphological factors that influence the cartilage, menisci, and ACL have been reported.[38] The geometry of the proximal tibial plateau has an influence on the biomechanics of the tibiofemoral joint in terms of translation, location of the instantaneous centre of rotation, screw-home mechanism, and strain biomechanics of the knee ligament.[18,19] An important characteristic of the tibial plateau is its posterior slope. When this characteristic is considered in association with a large compressive joint-reaction force such as that produced during weight-bearing activities, the force may have an anteriorly directed shear force component that acts to produce a corresponding anteriorly directed translation of the tibia.[18,20] Biomechanical studies have shown that a steep MTS leads to increased ATT under load, which may increase the forces acting on the menisci.[18,20–24] Furthermore, a complex MM tear was reported to be more frequently associated with a biconcave medial tibial plateau,[25] and a shallower MTS and LTS may result in impingement of MM posterior horn and LM anterior horn, respectively.[26] Recently, a comprehensive study reported risk factors for ramp lesions in the ACL-deficient knee, which included bone contusion on the posterior medial tibial plateau, chronic injury, steeper medial tibial and meniscal slope, gradual LTS, and varus knee alignment >3°. However, few studies have analysed the association between tibial geometry and ramp lesion of the MM concomitant with an ACL injury.

In the present study, only women were selected for standardisation because women have a steeper MTS than men,[29] and a bucket handle tear was not detected in either group because we considered that the patients turned down sports activity after injury. Subsequently, we evaluated MTS, MTPD, and CTS using the same method used by Hudek et al. and Hashemi et al.[29,31] because of its proven reproducibility.[32] Our results of MTS, MTPD, and CTS are consistent with the results of previous studies that used the

same measurement modality and method.[29,39] Significantly steeper MTS values were observed in group AM than in group A ($P < 0.01$). Moreover, the sensitivity/specificity were 0.73/0.76 when the cut-off value was set at 5.0°.

The present findings suggest that biomechanical alteration in the posterior rollback of the femur is likely caused by a steep MTS, resulting in impingement of MM posterior horn and predisposing the MM to tear in ACL-deficient knee. This association can be well explained by biomechanical and clinical data. From a biomechanical view, the tibial slope produces an anteriorly directed shear force when a compressive load is applied to the knee joint, resulting in an anterior translation of the tibia relative to the femur.[18,20—24] However, the biomechanical effect of the tibial slope might be even more complex, as characterisation of the surface geometry of the tibial plateau with a single slope represents an insufficient approximation of its three-dimensionality.[29] If knees with similar articular cartilage thickness and meniscus were compared, a deeper medial tibial plateau would constrain the femoral condyle to a greater extent and may result in increased resistance to the tibial translation relative to the femur.[29,39] Therefore, we believe that a steep MTS may be an anatomic risk factor for ramp lesion of the MM in an ACL-deficient knee.

The findings of the present study may have several clinical implications. The pre-operative diagnosis of MM posterior segment tear, including ramp lesion and other injuries are often missed on preoperative MRI, although MRI in the knee-flexed position is useful to detect ramp lesion of the MM.[10,11] The results of the present study suggest that a high index of suspicion for an MM tear is especially necessary for patients with a steep MTS detected by plain radiographs, computed tomography, or MRI. In daily clinical work, surgeons should prepare for MM repair in combination with ACLR, especially in patients with MTS $\geq5°$.

This study has several limitations, which must be considered when interpreting our results. First, the study design was retrospective with a small sample size; therefore, the validity of our findings is limited. However, the statistical power for the endpoint was acceptable with this sample size. Second, only Asian female patients with ACL injuries were evaluated; therefore, the results may not allow generalisation to males and females of other ethnicities. Third, biomechanical studies were not performed in patients with various MTS values. Finally, other factors that increase the risk for MM posterior root tear such as LTS may exist, which were not examined in this study.

Conclusions

A steep posterior slope of the medial tibial plateau is a risk factor for ramp lesion of the MM associated with an ACL injury. Especially in patients with MTS $\geq5.0°$, an occult ramp lesion of the MM should be strongly suspected and surgeons should prepare for MM repair in combination with ACLR. Further research for other factors associated with ramp lesion of the MM or MTS biomechanics is warranted.

Funding

Authors' contributions

Takayuki Furumatsu designed the study. Yuki Okazaki and Takaaki Hiranaka contributed to the analysis and interpretation of data. All authors have contributed to data collection and interpretation and critically reviewed the manuscript. All authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Acknowledgements

References

1. Shelbourne KD, Rask BP. The sequelae of salvaged nondegenerative peripheral vertical medial meniscus tears with anterior cruciate ligament reconstruction. *Arthrosc J Arthrosc Relat Surg: Off Publ Arthrosc Assoc North Am Int Arthrosc Assoc.* 2001;17(3):270—274.
2. Furumatsu T, Miyazawa S, Tanaka T, Okada Y, Fujii M, Ozaki T. Postoperative change in medial meniscal length in concurrent all-inside meniscus repair with anterior cruciate ligament reconstruction. *Int Orthop.* 2014;38(7):1393—1399.
3. Seon JK, Gadikota HR, Kozanek M, Oh LS, Gill TJ, Li G. The effect of anterior cruciate ligament reconstruction on kinematics of the knee with combined anterior cruciate ligament injury and subtotal medial meniscectomy: an in vitro robotic investigation. *Arthrosc J Arthrosc Relat Surg: Off Publ Arthrosc Assoc North Am Int Arthrosc Assoc.* 2009;25(2):123—130.
4. Musahl V, Citak M, O'Loughlin PF, Choi D, Bedi A, Pearle AD. The effect of medial versus lateral meniscectomy on the stability of the anterior cruciate ligament-deficient knee. *Am J Sports Med.* 2010;38(8):1591—1597.
5. Bell KM, Rahnemai-Azar AA, Irarrazaval S, et al. In situ force in the anterior cruciate ligament, the lateral collateral ligament, and the anterolateral capsule complex during a simulated pivot shift test. *J Orthop Res: Off Publ Orthop Res Soc.* 2018;36(3):847—853.
6. Kim D, Asai S, Moon CW, et al. Biomechanical evaluation of anatomic single- and double-bundle anterior cruciate ligament reconstruction techniques using the quadriceps tendon. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(3):687—695. official journal of the ESSKA.
7. Beaufils P, Hulet C, Dhenain M, Nizard R, Nourissat G, Pujol N. Clinical practice guidelines for the management of meniscal lesions and isolated lesions of the anterior cruciate ligament of the knee in adults. *Orthop Traumatol Surg Res : OTSR.* 2009;95(6):437—442.
8. Pujol N, Beaufils P. Healing results of meniscal tears left in situ during anterior cruciate ligament reconstruction: a review of clinical studies. *Knee Surg Sports Traumatol Arthrosc: Off J ESSKA.* 2009;17(4):396—401.
9. Sarraj M, Coughlin RP, Solow M, et al. Anterior cruciate ligament reconstruction with concomitant meniscal surgery: a systematic review and meta-analysis of outcomes. *Knee Surg Sports Traumatol Arthrosc: Off J ESSKA.* 2019;27(11):3441—3452.
10. Okazaki Y, Furumatsu T, Okamoto S, et al. Diagnostic performance of open MRI in the flexed knee position for the detection of medial meniscus ramp lesions. *Skeletal Radiol.* 2020;49(11):1781—1788.
11. Bumberger A, Koller U, Hofbauer M, et al. Ramp lesions are frequently missed in ACL-deficient knees and should be repaired in case of instability. *Knee Surg Sports Traumatol Arthrosc: Off J ESSKA.* 2020;28(3):840—854.
12. Hashemi J, Chandrashekar N, Mansouri H, et al. Shallow medial tibial plateau and steep medial and lateral tibial slopes: new risk factors for anterior cruciate ligament injuries. *Am J Sports Med.* 2010;38(1):54—62.
13. Song GY, Zhang H, Zhang J, et al. Greater static anterior tibial subluxation of the lateral compartment after an acute anterior cruciate ligament injury is associated with an increased posterior tibial slope. *Am J Sports Med.* 2018;46(7):1617—1623.
14. Cinotti G, Sessa P, Ragusa G, et al. Influence of cartilage and menisci on the sagittal slope of the tibial plateaus. *Clin Anat.* 2013;26(7):883—892.
15. Luczkiewicz P, Daszkiewicz K, Witkowski W, Chroscielewski J, Zarzycki W. Influence of meniscus shape in the cross sectional plane on the knee contact mechanics. *J Biomech.* 2015;48(8):1356—1363.
16. Song GY, Liu X, Zhang H, et al. Increased medial meniscal slope is associated with greater risk of ramp lesion in noncontact anterior cruciate ligament injury. *Am J Sports Med.* 2016;44(8):2039—2046.
17. Wu J, Huang JM, Zhao B, Cao JG, Chen X. Risk factors comparison for radial and horizontal tears. *J Knee Surg.* 2016;29(8):679—683.
18. Dejour H, Bonnin M. Tibial translation after anterior cruciate ligament rupture. Two radiological tests compared. *J Bone Joint Surg.* 1994;76(5):745—749.
19. Beynnon B, Yu J, Huston D, et al. A sagittal plane model of the knee and cruciate ligaments with application of a sensitivity analysis. *J Biomech Eng.* 1996;118(2):227—239.
20. Giffin JR, Vogrin TM, Zantop T, Woo SL, Harner CD. Effects of increasing tibial slope on the biomechanics of the knee. *Am J Sports Med.* 2004;32(2):376—382.

21. Shelburne KB, Kim HJ, Sterett WI, Pandy MG. Effect of posterior tibial slope on knee biomechanics during functional activity. *J Orthop Res: Off Publ Orthop Res Soc*. 2011;29(2):223–231.
22. Agneskirchner JD, Hurschler C, Stukenborg-Colsman C, Imhoff AB, Lobenhoffer P. Effect of high tibial flexion osteotomy on cartilage pressure and joint kinematics: a biomechanical study in human cadaveric knees. Winner of the AGA-DonJoy Award 2004. *Arch Orthop Trauma Surg*. 2004;124(9):575–584.
23. Marouane H, Shirazi-Adl A, Hashemi J. Quantification of the role of tibial posterior slope in knee joint mechanics and ACL force in simulated gait. *J Biomech*. 2015;48(10):1899–1905.
24. Meyer EG, Haut RC. Excessive compression of the human tibio-femoral joint causes ACL rupture. *J Biomech*. 2005;38(11):2311–2316.
25. Barber FA, Getelman MH, Berry KL. Complex medial meniscus tears are associated with a biconcave medial tibial plateau. *Arthrosc J Arthrosc Relat Surg*. 2017;33(4):783–789. official publication of the Arthroscopy Association of North America and the International Arthroscopy Association.
26. Khan N, McMahon P, Obaid H. Bony morphology of the knee and non-traumatic meniscal tears: is there a role for meniscal impingement? *Skeletal Radiol*. 2014;43(7):955–962.
27. Kim SH, Seo HJ, Seo DW, Kim KI, Lee SH. Analysis of risk factors for ramp lesions associated with anterior cruciate ligament injury. *Am J Sports Med*. 2020;48(7):1673–1681.
28. Thaunat M, Fayard JM, Guimaraes TM, Jan N, Murphy CG, Sonnery-Cottet B. Classification and surgical repair of ramp lesions of the medial meniscus. *Arthrosc Tech*. 2016;5(4):e871–e875.
29. Hashemi J, Chandrashekar N, Gill B, et al. The geometry of the tibial plateau and its influence on the biomechanics of the tibiofemoral joint. *J Bone Joint Surg Am*. 2008;90(12):2724–2734.
30. Schneider A, Arias C, Bankhead C, Gaillard R, Lustig S, Servien E. Greater medial tibial slope is associated with increased anterior tibial translation in females with an ACL-deficient knee. *Knee Surg Sports Traumatol Arthrosc: Off J ESSKA*. 2020;28(6):1901–1908.
31. Hudek R, Schmutz S, Regenfelder F, Fuchs B, Koch PP. Novel measurement technique of the tibial slope on conventional MRI. *Clin Orthop Relat Res*. 2009;467(8):2066–2072.
32. Lipps DB, Wilson AM, Ashton-Miller JA, Wojtys EM. Evaluation of different methods for measuring lateral tibial slope using magnetic resonance imaging. *Am J Sports Med*. 2012;40(12):2731–2736.
33. Weinberg DS, Williamson DF, Gebhart JJ, Knapik DM, Voos JE. Differences in medial and lateral posterior tibial slope: an osteological review of 1090 tibiae comparing age, sex, and race. *Am J Sports Med*. 2017;45(1):106–113.
34. Kanda Y. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. *Bone Marrow Transplant*. 2013;48(3):452–458.
35. Okazaki Y, Furumatsu T, Miyazawa S, et al. Meniscal repair concurrent with anterior cruciate ligament reconstruction restores posterior shift of the medial meniscus in the knee-flexed position. *Knee Surg Sports Traumatol Arthrosc: Off J ESSKA*. 2019;27(2):361–368.
36. Katagiri H, Miyatake K, Nakagawa Y, et al. The effect of a longitudinal tear of the medial meniscus on medial meniscal extrusion in anterior cruciate ligament injury patients. *Knee*. 2019;26(6):1292–1298.
37. Narazaki S, Furumatsu T, Tanaka T, et al. Postoperative change in the length and extrusion of the medial meniscus after anterior cruciate ligament reconstruction. *Int Orthop*. 2015;39(12):2481–2487.
38. Takahashi K, Hashimoto S, Kiuchi S, et al. Bone morphological factors influencing cartilage degeneration in the knee. *Mod Rheumatol*. 2018;28(2):351–357.
39. Okazaki Y, Furumatsu T, Kodama Y, et al. Steep posterior slope and shallow concave shape of the medial tibial plateau are risk factors for medial meniscus posterior root tears. *Knee Surg Sports Traumatol Arthrosc: Off J ESSKA*. 2019.