Factors Influencing the Progression of Patellofemoral Articular Cartilage Damage After Anterior Cruciate Ligament Reconstruction

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**Background:** Although anterior cruciate ligament reconstruction (ACLR) can restore the stability and function of the knee joint, patellofemoral joint cartilage damage still progresses. Currently, the clinically important factors that lead to the progression of patellofemoral articular cartilage damage are not fully understood.

**Purpose:** To investigate the factors that affect the progression of patellofemoral articular cartilage damage after ACLR.

**Study Design:** Cohort study; Level of evidence, 2.

**Methods:** Among 160 patients who underwent ACLR between January 2015 and December 2019, the authors evaluated 129 patients for at least 1 year after surgery. Within 1 week before ACLR and at the last follow-up, patients underwent subjective functional assessment and magnetic resonance imaging evaluations of articular cartilage damage (modified Outerbridge assessment). At the last follow-up, the side-to-side difference on KT-2000 arthrometer and bilateral quadriceps muscle strength were measured. Univariate and multivariate logistic regression analyses were performed.

**Results:** The mean follow-up was 24.69 ± 10.74 months. Progression of patellar cartilage damage from preoperatively to final follow-up was seen in 45 patients ($P < .001$). Logistic regression analysis revealed that the follow-up period ($P = .047$; odds radio (OR) = 0.953) (improvement of patellar cartilage damage with longer follow-up), partial lateral meniscal resection ($P = .004$; OR = 6.929), partial medial meniscal resection ($P = .004$; OR = 6.032), and quadriceps muscle strength < 80% of the contralateral side ($P = .001$; OR = 4.745) were risk factors for the progression of patellar cartilage damage.

**Conclusion:** Cartilage damage at the patellofemoral joint, especially the patellar cartilage, still progresses after ACLR. At a mean follow-up of 24.69 months after ACLR, partial meniscal resection and quadriceps femoris muscle strength were found to be the main risk factors for the progression of patellofemoral articular cartilage damage after ACLR.

**Keywords:** anterior cruciate ligament reconstruction; knee; patellofemoral joint; patellar articular cartilage

Rupture of the anterior cruciate ligament (ACL) can cause knee joint instability and damage the articular cartilage. ACL reconstruction (ACLR) can restore the stability of the knee joint and relieve patients' clinical symptoms as well as improve motor function. Although a study has reported the development of tibiofemoral osteoarthritis after ACLR, 11% to 90% of patients develop patellofemoral arthritis after ACLR. Imaging patellofemoral osteoarthritis may be more common than tibiofemoral osteoarthritis and is associated with worse knee-related symptoms, including anterior knee pain and decreased functional performance. Gong et al reported the occurrence of patellofemoral articular cartilage damage at an average follow-up of 17.3 months from single-bundle reconstruction of the ACL to the second arthroscopy. Nakamae et al reported that 174 patients underwent a second arthroscopy after an anatomic ACLR. Variables such as age, sex, body mass index, ACLR technique, and meniscal conditions were included in the regression analysis for progression of articular cartilage damage in the femoral condyle and tibial plateau. The authors found that partial meniscal resection was closely related to the progression of articular cartilage damage. Niki et al analyzed the factors that affect anterior knee pain after ACLR and concluded that knee extension deficits are an important risk factor for knee pain before 3 months postoperatively.
Although patellofemoral articular cartilage damage could lead to anterior knee pain, their study did not directly investigate the factors affecting the progression of this damage.

At present, the factors that affect the progression of patellofemoral articular cartilage damage after ACLR are not fully understood, and a more comprehensive analysis is lacking. To address this gap in knowledge, this study aimed to explore the factors that affect progression of patellofemoral cartilage damage after ACLR.

METHODS

Participants

This study was approved by the ethics committee of our hospital, and all participants signed an informed consent form before participating. All patients who underwent ACLR between January 2015 and December 2019 were invited to participate in this study. Included were patients who underwent single-bundle ACLR, with no history of surgery performed on the affected knee, with a normal contralateral knee, and with no posterior cruciate ligament insufficiency. Excluded were patients with lateral discoid meniscus, those with grade 3 medial or lateral instability, and those who underwent ACLR combined with articular cartilage surgery. Patient selection details are illustrated in Figure 1. At the final follow-up, 129 patients were included.

Surgical Technique

A senior surgeon performed all surgeries using the arthroscopic single-bundle autologous hamstring tendon ACLR technique. Anatomic reconstruction technology was employed to create tibial and femoral bone canals. After pulling the graft into the bone canal, the surgeon used the EndoButton fixation device (Smith & Nephew) to fix the femoral side, whereas the tibial side was fixed with absorbable compression screws (Smith & Nephew). The meniscal damage was repaired via meniscal repair, meniscal file, or a partial meniscal resection. Radial tears, horizontal tears, or tears at the edges of the surrounding menisci were treated with a partial meniscal resection. If the longitudinal tear was in the red-red or red-white zone, the total internal repair technique of the arthroscopic suture system (FasT-Fix; Smith & Nephew) was used. A meniscal file was used to treat minor meniscal injuries.

After the surgery, the knee joint was fixed in the extension position via a brace. Four days later, the patients started knee flexion exercises and weightbearing which was gradually increased, with knee flexion at 90° in the first week and at 120° with full weightbearing after 6 weeks. The use of a knee brace was not required at home. Knee flexion had returned to normal at 8 to 12 weeks after the surgery. The patients were permitted to start jogging without a brace at 3 months postoperatively and to run, jump, and swim at 4 to 6 months postoperatively. A special adaptability training was conducted for 3 months, such that the patient could participate in intense special training and sports competitions at 10 months after the surgery.

Evaluation of Articular Cartilage Damage

Magnetic resonance imaging (MRI) evaluation of articular cartilage damage was performed using the modified Outerbridge grading system. The modified Outerbridge score was denoted as follows: 0, intact cartilage with normal signal; 1,
increased signal intensity with no loss of cartilage thickness; 2, loss of <50% of the cartilage thickness; 3, loss of >50% of the cartilage thickness without exposed bone; and 4, full-thickness cartilage loss with exposed bone. The progression of cartilage damage was defined as any increase in Outerbridge score from within 1 week before ACLR to the last follow-up. All of the measurements were taken by 3 experienced radiologists who were blinded to the patient’s condition, and repeated measurements were performed at 2 time points that were at least 1 month apart.

MRI was performed via a 3.0-T MRI system (Magnetom Skyra; Siemens Healthcare) using a phased-array knee coil. Patients were placed in the supine position with the knee fully extended. The MRI parameters included sagittal T1 fast spin echo (FSE), sagittal fat-saturated proton density-weighted FSE, and transverse fat-saturated proton density-weighted FSE (Appendix Table A1).

Clinical Function Assessments
At 1 week before the ACLR and at the last follow-up, the Lysholm scale, International Knee Documentation Committee, and Tegner scores were used for functional assessment by an experienced orthopaedic surgeon (H.H.) on the same day.

At the last follow-up, the patients underwent bilateral knee examination using a KT-2000 arthrometer (Med-Metric). The side-to-side anterior tibial translation difference, measured using a force of 133 N at 20° of knee flexion, was recorded. A Biodex System III isokinetic tester (Biodex Medical Systems) was used to perform isokinetic muscle strength tests on both quadriceps femoris muscles of each patient at the last follow-up. The peak torque (PT) of the quadriceps femoris (representing the maximum strength of the muscle) was recorded. The PT ratio of the quadriceps femoris was calculated as follows: affected side/healthy side. It was then divided into ratios <80% and ≥80%. This study measured the muscle strength at an angular velocity of 60 deg/s.

Statistical Analysis
SPSS Statistics Version 19.0 (IBM Corp) was used for statistical analysis between patients who showed progression of cartilage damage and those who did not. Univariate analysis was first used to analyze the risk factors that were considered to affect the progression of cartilage damage. The chi-square test or Fisher exact test was used to compare qualitative variables, and the independent-samples Student t test or 2-sample Wilcoxon rank sum test was used to compare quantitative variables. Multiple logistic regression analysis was used to examine the correlation among the identified factors, and the risk was estimated using odds ratios with 95% CIs. The significance threshold of the test was set at \( P < .05 \). The interobserver and intraobserver reliability for the MRI evaluation of articular cartilage damage were assessed using the intraclass correlation coefficient (ICC); reliability was interpreted as poor if ICC < 0.4, marginal if 0.4 ≤ ICC ≤ 0.75, and good if ICC > 0.75.

We calculated a priori the sample sizes needed to achieve sufficient power for comparison of quadriceps strength between the patients with cartilage damage progression (observation group) and those without (control group). Pre-experiment results showed that the proportion of patients with a PT ratio of the quadriceps femoris <80% was 40% in the control group and 70% in the observation group. For hypothesis testing, type 1 error (α) was set as .05 using a 2-sided test and type 2 error (β) was set as 0.1 (ie, power = 0.9). The sample size of the 2 groups was set in a 2:1 ratio, and the sample sizes calculated using PASS software (Version 15.0; NCSS) were 84 for the control group and 42 for the observation group.

RESULTS
A total of 129 participants between the ages of 18 and 46 years (mean age, 26.98 years) were included in the final follow-up (47 female and 82 male patients). The mean follow-up was 24.69 ± 10.74 months (range, 12-50 months). The data of the participants are shown in Table 1.

A total of 45 patients had progression of patellar cartilage damage on MRI scans from within 1 week before ACLR to the last follow-up, and the difference was statistically significant (\( P < .001 \)) (Appendix Table A2). In addition, 18 patients had MRI progression of trochlear cartilage damage from within 1 week before ACLR to the last follow-up, but the difference was not statistically significant (\( P = .519 \)). In the MRI evaluation of articular cartilage damage, the interobserver and intraobserver reliability ICCs were 0.83 and 0.88, respectively, indicating good reliability.

Four factors were significantly related to the progression of patellar cartilage damage after ACLR: follow-up period (\( P = .001 \)), PT ratio of the quadriceps femoris (\( P < .001 \)), lateral meniscal injury (\( P = .004 \)), and medial meniscal injury (\( P = .046 \)) (Table 2). No factors were significantly related to the progression of the femoral trochlear cartilage damage after ACLR (Appendix Table A3).

In the logistic regression model, 4 previously identified factors related to the progression of patellar cartilage damage were introduced (ie, follow-up period, PT ratio of the quadriceps femoris, lateral meniscal injury, and medial meniscal injury). The results showed that follow-up period was significantly negatively correlated with the progression of patellar cartilage damage. In addition, a PT ratio of the quadriceps femoris <80%, partial meniscectomy of the lateral meniscus, and partial meniscectomy of the medial meniscus were significant risk factors for the progression of patellar cartilage damage (Table 3).

DISCUSSION
We found in this study that after ACLR, MRI examinations revealed postoperative progression of patellofemoral articular cartilage injuries, mainly on the patellar side, that was significantly related to postoperative time, meniscal damage, and quadriceps femoris muscle strength.
Our study found that quadriceps muscle strength <80% of the contralateral side was associated with the progression of patellofemoral cartilage damage after ACLR. Restoring the muscle strength of the affected quadriceps femoris muscle to >80% of the strength of the quadriceps femoris muscle on the healthy side may reduce the occurrence and progression of patellar cartilage damage after ACLR. Keays et al12 found that, in 56 patients who were followed up for an average of 6 years after ACLR, those with a smaller quadriceps femoris to hamstring muscle strength ratio had a higher incidence of osteoarthropathy in the tibiofemoral joint than in the patellofemoral joint. A study on knee osteoarthritis found that enhancing quadriceps femoris muscle strength can reduce the damage to the cartilage in the patellofemoral joint in patients with knee osteoarthritis; however, this has no obvious effect on the cartilage in the tibiofemoral joint.22

The study findings also showed that although recovery of quadriceps femoris muscle strength can significantly reduce the damage to the patellar cartilage after ACLR, it may not have a significant effect on damage to the trochlear cartilage. The reason for this finding is not clear. It may be related to the change in the quadriceps femoris muscle strength that subsequently affects the trajectory of the patella, which in turn affects the patellar articular cartilage damage. However, this conclusion requires further study.

After ACL damage, the levels of many cytokines, such as tumor necrosis factor α, interleukin 1β, and matrix metalloproteases 1 and 13, immediately increase in the joint.9 Tumor necrosis factor α is related to the increase in apoptotic caspase pathways in the chondrocytes.14 Although the levels of these cytokines slowly decline over time, ACL-deficient knees continue to show increased levels of inflammatory cytokines, at least 1 year after damage.5,8 The adjustment of the initial inflammatory response after ACL damage may have a potentially lasting effect on early knee cartilage degeneration.9 However, the potential reduction of the effect of ACL damage on joints after >1 year after ACLR remains to be further studied. Our study found that follow-up period (range, 12-50 months) was significantly negatively correlated with the progression of patellar cartilage damage, which may be because the effect of ACLR on articular cartilage metabolism is eliminated after >1 year postoperatively and because damaged cartilage repairs itself. Further studies are needed to confirm this finding, and a longer follow-up might provide clearer results.

Limitations

This study had several limitations. First, we lacked preoperative muscle strength assessments and preoperative KT-2000 arthrometer measurements for the patients, which might have affected the results. Second, the participants included those who had undergone a second MRI examination 1 year after surgery because they might have had knee discomfort and would prefer to undergo an MRI review at the time of follow-up. This preference to undergo a second MRI examination might have overestimated the changes in the cartilage. Third, the age range of the patients in our

### TABLE 1

Data of the Participants (N = 129)a

| Variable               | Value                      |
|------------------------|----------------------------|
| Age, y                 | 26.98 ± 6.05 (18-46)       |
| Sex                    |                            |
| Female                 | 47                         |
| Male                   | 82                         |
| Body mass index        | 22.55 ± 3.80 (16.30-29.00) |
| Waist circumference, cm| 77.49 ± 5.36 (61.95)       |
| Metabolic syndrome     |                            |
| Yes                    | 0                          |
| No                     | 129                        |
| Exerciseb              |                            |
| Yes                    | 101                        |
| No                     | 28                         |
| Hypertension           |                            |
| Yes                    | 5                          |
| No                     | 124                        |
| Diabetes               |                            |
| Yes                    | 2                          |
| No                     | 127                        |
| Smoker                 |                            |
| Yes                    | 18                         |
| No                     | 111                        |
| Surgical delay, wk     | 55.73 ± 62.83 (1-500)      |
| Follow-up period, mo   | 24.69 ± 10.74 (12-50)      |
| Lateral meniscus       |                            |
| Normal                 | 51                         |
| Minor damage           | 27                         |
| Meniscal repair        | 32                         |
| Partial meniscectomy   | 19                         |
| Medial meniscus        |                            |
| Normal                 | 62                         |
| Minor damage           | 28                         |
| Meniscal repair        | 15                         |
| Partial meniscectomy   | 24                         |

aValues are presented as mean ± SD (range) or frequency.
bRegular exercise: ≥3 episodes per week, with at least 30 minutes of exercise per episode.

ACLR provides stability to the affected knee and further protects the knee cartilage from secondary damage caused by damaged ligaments.3,7,18,26 However, there is evidence that ACLR cannot completely prevent the progression of osteoarthritis.2,23 Meniscectomy is recognized as an important risk factor for posttraumatic osteoarthritis in ACLR.10 A study by the Multicenter Orthopaedic Outcomes Network Knee Group17 of 421 patients with follow-up knee radiographs at least 2 years after ACLR showed that meniscal repair and partial meniscectomy were both associated with worse radiographic posttraumatic osteoarthritis in the medial and lateral compartments. Furthermore, meniscectomy had a greater effect on worse posttraumatic osteoarthritis than did meniscal repair. A systematic review by van Meer et al24 confirmed the importance of preservation of the meniscus for preventing development of osteoarthritis in patients who underwent ACLR. Our study showed that both medial and lateral partial meniscectomies were significant risk factors for the progression of patellar cartilage damage after ACLR.
### TABLE 2
Factors Related to Progression of Patellar Cartilage Damage (Univariate Analysis)

| Progression of Patellar Cartilage Damage | No (n = 84) | Yes (n = 45) | t     | P     |
|------------------------------------------|------------|-------------|-------|-------|
| Age, y                                   | 26.89 ± 6.01 | 27.13 ± 6.20 | -0.214 | .831  |
| Body mass index                          | 22.55 ± 3.85 | 22.53 ± 3.73 | 0.040  | .968  |
| Surgical delay, wk                       | 50.79 ± 55.83 | 64.96 ± 73.96 | -1.223 | .224  |
| Follow-up, mo                            | 26.73 ± 11.41 | 20.89 ± 8.19  | 3.347  | .001  |
| ATTD, mm                                 | 3.05 ± 1.24  | 2.91 ± 1.50  | 0.521  | .604  |
| Tegner score                             |             |             |       |       |
| Within 1 wk before ACLR                  | 2.00 ± 0.78  | 2.16 ± 0.93  | -1.012 | .313  |
| Last follow-up                           | 6.60 ± 1.03  | 6.29 ± 1.12  | 1.560  | .121  |
| IKDC score                               |             |             |       |       |
| Within 1 wk before ACLR                  | 42.30 ± 5.65 | 41.89 ± 6.21 | 0.378  | .706  |
| Last follow-up                           | 89.32 ± 3.42 | 88.84 ± 5.11 | 0.632  | .528  |
| Lysholm score                            |             |             |       |       |
| Within 1 wk before ACLR                  | 51.48 ± 5.50 | 52.44 ± 5.35 | -0.961 | .338  |
| Last follow-up                           | 91.86 ± 3.58 | 91.76 ± 3.74 | 0.151  | .880  |

Patients With Progression of Patellar Cartilage Damage (n = 45)

| Sex            | 0.287 | .592 |
|----------------|-------|------|
| Female         | 36.59 |      |
| Male           | 31.91 |      |

PT ratio of the quadriceps femoris

| <80%           | 50.85 | 21.43 |
|----------------|-------|-------|
| ≥80%           |       |       |

Lateral meniscal injury

| Normal         | 21.57 |      |
|----------------|-------|------|
| Minor damage   | 33.33 |      |
| Meniscal repair| 37.50 |      |
| Partial meniscectomy | 68.42 |      |

Medial meniscal injury

| Normal meniscus | 27.42 |      |
|-----------------|-------|------|
| Minor damage    | 28.57 |      |
| Meniscal repair | 40.00 |      |
| Partial meniscectomy | 58.33 |      |

| Data are presented as mean ± SD or percentage. Boldface P values indicate statistical significance (P < .05). ACLR, anterior cruciate ligament reconstruction; ATTD, anterior tibial translation side-to-side difference; IKDC, International Knee Documentation Committee; PT, peak torque. |

### TABLE 3
Logistic Regression Analysis of All Important Factors Identified in the Univariate Analysis

| Regression Coefficient | P     | OR (95% CI) |
|------------------------|-------|------------|
| Follow-up period       | -0.048| .047       | 0.953 (0.909-0.999) |
| PT ratio of the quadriceps femoris |       |            |                |
| ≥80%                   | -      | -          | 1 (referent)   |
| <80%                   | 1.557  | .001       | 4.745 (1.861-12.100) |
| Lateral meniscal injury|       |            |                |
| Normal                 | -      | -          | 1 (referent)   |
| Minor damage           | 0.46   | .444       | 1.585 (0.488-5.145) |
| Meniscal repair        | 0.931  | .114       | 2.537 (0.799-8.055) |
| Partial meniscectomy   | 1.936  | .004       | 6.929 (1.826-26.302) |
| Medial meniscal injury |       |            |                |
| Normal                 | -      | -          | 1 (referent)   |
| Minor damage           | 0.144  | .814       | 1.154 (0.348-3.827) |
| Meniscal repair        | 1.006  | .155       | 2.734 (0.684-10.937) |
| Partial meniscectomy   | 1.797  | .004       | 6.032 (1.765-20.609) |

*Boldface P values indicate statistical significance (P < .05). OR, odds ratio; PT, peak torque. Dashes refer to reference.*
study was large (18–46 years), which might have affected the results. However, the effect of age on the progression of cartilage damage was not significant. Finally, the time interval from the ACLR to the last follow-up was quite wide. However, our sample size did not allow us to analyze different potential characteristics at different time points.

CONCLUSION

Our findings suggest that damage of the patellofemoral articular cartilage is significantly aggravated after ACLR, which may manifest mainly in the patellar cartilage and may be closely related to postoperative time, quadriceps femoris muscle strength, and partial meniscal resection. The meniscus should be preserved as much as possible during the operation, and great importance should be focused on quadriceps femoris muscle strength exercises after surgery.

REFERENCES

1. Briggs KK, Kocher MS, Rodkey WG, Steadman JR. Reliability, validity, and responsiveness of the Lysholm knee score and Tegner activity scale for patients with meniscal damage of the knee. J Bone Joint Surg Am. 2006;88(4):696-705. doi:10.2106/JBJS.E.00339
2. Chen T, Wang S, Li Y, Ai C, Jiang F, Chen S. Radiographic osteoarthritis prevalence over ten years after anterior cruciate ligament reconstruction. Int J Sports Med. 2019;40(11):693-695. doi:10.1055/a-0902-8539
3. Cheung EC, DiLallo M, Feeley BT, Lansdown DA. Osteoarthritis and ACLR—myths and risks. Curr Rev Musculoskelet Med. 2020;13(1):115-122. doi:10.1007/s12178-019-09596-w
4. Crawford K, Briggs KK, Rodkey WG, Steadman JR. Reliability, validity, and responsiveness of the IKDC score for meniscus injuries of the knee. Arthroscopy. 2007;23(8):839-844. doi:10.1016/j.arthro.2007.02.005
5. Edd SN, Giori NJ, Andriacchi TP. The role of inflammation in the initiation of osteoarthritis after meniscal damage. J Biomech. 2015;48(8):1420-1426. doi:10.1016/j.jbiomech.2015.02.035
6. Ghodadra N, Mall NA, Karas V, et al. Articular and meniscal pathology associated with primary anterior cruciate ligament reconstruction. J Knee Surg. 2013;26(3):185-193. doi:10.1055/s-0032-1327450
7. Gong X, Jiang D, Wang YJ, et al. Cartilage damage after acute, isolated anterior cruciate ligament tear: a second-look arthroscopic evaluation. Am J Sports Med. 2015;43(9):1543-1549. doi:10.1177/0363546515588064
8. Harkey MS, Luc BA, Golightly YM, et al. Pathogenetic mechanisms of posttraumatic osteoarthritis: opportunities for early intervention. Int J Clin Exp Med. 2011;4(4):285-298.
9. Haslauer CM, Elsaid KA, Fleming BC, Proffen BL, Johnson VM, Murray MM. Loss of extracellular matrix from articular cartilage is mediated by the synovium and ligament after anterior cruciate ligament damage. Osteoarthritis Cartilage. 2013;21(12):1950-1957. doi:10.1016/j.joca.2013.09.003
10. Hiranaka T, Furumatsu T, Kamatsuki Y, et al. Early chondral damage following meniscus repairs with anterior cruciate ligament reconstruction. Asia Pac J Sports Med Arthrosc Rehabil Technol. 2020;20(1):1-5. doi:10.1016/j.apsmart.2020.01.001
11. Ishibashi Y, Kimura Y, Sasaki E, Sasaki S, Yamamoto Y, Tsuda E. Acute primary repair of extraarticular ligaments and staged surgery in multiple ligament knee injuries. J Orthop Traumatol. 2020;21(1):18. doi:10.1186/s10195-020-00557-5
12. Keays SL, Newcombe PA, Bullock-Saxton JE, Bullock MI, Keays AC. Factors involved in the development of osteoarthritis after anterior cruciate ligament surgery. Am J Sports Med. 2010;38(3):455-463. doi:10.1177/0363546509350914
13. Kim CW, Hosseini A, Lin L, et al. Quantitative analysis of T2 relaxation times of the patellofemoral joint cartilage 3 years after anterior cruciate ligament reconstruction. J Orthop Transl. 2018;12:85-92. doi:10.1016/j.jot.2017.06.002
14. Kramer WC, Hendricks KJ, Wang J. Pathogenetic mechanisms of osteoarthritis, and patellofemoral osteoarthritis outcomes following ACLR—myths and risks. Am J Sports Med. 2011;39(12):2595-2603. doi:10.1177/0363546511424720
15. McCarthy MM, Strickland SM. Patellofemoral pain: an update on diagnostic and treatment options. Curr Rev Musculoskelet Med. 2015;8(2):188-194. doi:10.1007/s12178-013-9159-x
16. MOON Knee Group; Jones MH, Oak SR, Andrisch JT, et al. Predictors of radiographic osteoarthritis 2 to 3 years after anterior cruciate ligament reconstruction: data from the MOON on-site nested cohort. Orthop J Sports Traumatol Arthrosc. 2019;20(8):1543-1549. doi:10.1007/s00167-011-1746-z
17. Murakami A, Takagi N, Iwamoto W, et al. Risk factors for progression of articular cartilage damage after anatomical anterior cruciate ligament reconstruction: a second-look arthroscopic evaluation. Bone Joint J. 2018;100-B(3):285-293. doi:10.1302/0301-620X.100B3.BJJ-2017-0837.R1
18. Naka K, Hakozi K, Iwamoto W, et al. Factors affecting anterior knee pain following anatomic double-bundle anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2020;28(8):2286-2292. doi:10.1177/0363546515588316
19. Nakamae A, Adachi N, Deie M, et al. Risk factors for progression of articular cartilage damage after anterior cruciate ligament reconstruction: a systematic review. J Bone Joint Surg Am. 2013;21(12):1950-1957. doi:10.1177/0363546511424720
20. Potter HG, Jain SK, Ma Y, Black BR, Fung S, Lyman S. Cartilage damage after acute, isolated anterior cruciate ligament tear: immediate and longitudinal effect with clinical/MRI follow-up. Am J Sports Med. 2012;40(2):276-285. doi:10.1177/0363546511423380
21. Stefaniak JJ, Guermazi A, Zhu Y. Quadriceps weakness, patella alta, and structural features of patellofemoral osteoarthritis. Arthritis Care Res (Hoboken). 2011;63(10):1391-1397. doi:10.1002/acr.20528
22. Ulstein S, Åreén A, Engebretsen L, Forssblad M, Lygre SH, Røtterud JH. Effect of concomitant cartilage lesions on patient-reported outcomes after anterior cruciate ligament reconstruction: a nationwide cohort study from Norway and Sweden of 8470 patients with 5-year follow-up. Orthop J Sports Med. 2018;6(7):232596718786219. doi:10.1177/232596718786219
23. van Eck CF, Kopf S, Irgang JJ, et al. Single-bundle versus double-bundle reconstruction for anterior cruciate ligament rupture: a meta-analysis—does anatomy matter? Arthroscopy. 2012;28(3):405-424. doi:10.1016/j.arthro.2011.11.021
24. van Meer BL, Meuffels DE, van Eijsden WA, Verhaar JA, Bierma-Zeinstra SM, Reijman M. Which determinants predict tibiofemoral and patellofemoral osteoarthritis after anterior cruciate ligament injury? A systematic review. Br J Sports Med. 2015;49(15):975-983. doi:10.1136/bjsports-2013-093258
25. Wang HJ, Ao YF, Jiang D, et al. Second-look arthroscopic evaluation of the articular cartilage after primary single-bundle and double-bundle anterior cruciate ligament reconstructions. Chin Med J (Engl). 2011;124(21):3551-3555.
26. Wang HJ, Ao YF, Jiang D, et al. Relationship between quadriceps strength and patellofemoral joint chondral lesions after anterior cruciate ligament reconstruction. Am J Sports Med. 2015;43(9):2286-2292. doi:10.1177/0363546515588316
APPENDIX

TABLE A1
Parameters for MRI Sequences

| Repetition time, ms | Sagittal T1 FSE | Sagittal Fat-Sat PD FSE | Coronal Fat-Sat Blade FSE | TRA Fat-Sat PD FSE |
|-------------------|----------------|-------------------------|--------------------------|------------------|
| 500               | 3050           | 4000                    | 3320                     |
| 11                | 34             | 63                      | 61                       |
| 16                | 16             | 16                      | 15                       |
| 3                 | 3              | 3                       | 3                       |
| 1                 | 1              | 1                       | 1                       |
| 1                 | 8              | 15                      | 11                      |

*Fat-Sat, fat saturated; FSE, fast spin echo; MRI, magnetic resonance imaging; PD, proton density-weighted; TRA, transverse.

APPENDIX TABLE A2
Patellar and Trochlear Cartilage Damage According to Modified Outerbridge Grade

| Outerbridge grade | Within 1 wk Before ACLR | At Last Follow-up | P  |
|-------------------|-------------------------|-------------------|----|
| 0                 | 61 (47.29)              | 41 (31.78)        | <.001|
| 1                 | 47 (36.43)              | 46 (35.66)        | 11 (8.53)     | 0.519 |
| 2                 | 19 (14.73)              | 33 (25.58)        | 9 (6.98)      | 3 (3.33)     |
| 3                 | 2 (1.55)                | 8 (6.20)          | 0 (0)         | 0 (0)         |
| 4                 | 0 (0)                   | 1 (0.78)          | 0 (0)         | 0 (0)         |
| Grade 0-1         | —                       | 15                | —             | 14            |
| Grade 0-2         | —                       | 5                 | —             | 0             |
| Grade 1-2         | —                       | 16                | —             | 1             |
| Grade 2-3         | —                       | 8                 | —             | 0             |
| Grade 3-4         | —                       | 1                 | —             | 0             |

*Data are presented as frequency (%). Boldface P value indicates statistical significance (P < .05). ACLR, anterior cruciate ligament reconstruction. Dashes indicate not applicable.

APPENDIX TABLE A3
Factors Related to Progression of Femoral Trochlear Cartilage Damage (Univariate Analysis)

| Progression of Femoral Trochlear Cartilage Damage | No (n = 111) | Yes (n = 18) | t    | P   |
|---------------------------------------------------|--------------|--------------|------|-----|
| Age, y                                            | 27.09 ± 6.07 | 26.28 ± 6.10 | 0.527| .599|
| Body mass index                                   | 22.48 ± 3.83 | 22.94 ± 3.65 | -0.473| .637|
| Surgical delay, wk                                | 52.09 ± 50.85| 78.17 ± 111.23| -0.978| .341|
| Follow-up period, mo                              | 25.14 ± 10.92| 21.89 ± 9.29 | 1.195| .234|
| ATTD, mm                                          | 3.01 ± 1.30  | 2.94 ± 1.55  | 0.19 | .85 |
| Tegner score                                      | 2.01 ± 0.80  | 2.33 ± 0.97  | -1.542| .126|
| Within 1 wk before ACLR                           | 6.51 ± 1.03  | 6.33 ± 1.28  | 0.662| .509|
| IKDC score                                        | 42.47 ± 5.58 | 40.22 ± 7.04 | 1.524| .13  |
| Within 1 wk before ACLR                           | 89.13 ± 3.81 | 89.33 ± 5.58 | -0.199| .842|

(continued)
### Progression of Femoral Trochlear Cartilage Damage

|                      | No (n = 111) | Yes (n = 18) | t     | P     |
|----------------------|-------------|-------------|-------|-------|
| Lysholm score        |             |             |       |       |
| Within 1 wk. before ACLR | 51.76 ± 5.35 | 52.17 ± 6.19 | -0.295 | .769  |
| Last follow-up       | 91.95 ± 3.41 | 91.00 ± 4.78 | 1.037  | .302  |
| **Patients With Progression of Femoral Cartilage Damage (n = 18)** | | | | |
| Sex                  |             |             | 0.087 | .768  |
| Female               | 14.63       |             |       |       |
| Male                 | 12.77       |             |       |       |
| PT ratio of the quadriceps femoris | | | | |
| <80%                 | 20.34       |             | 3.692 | .055  |
| ≥80%                 | 8.57        |             |       |       |
| Lateral meniscal damage |             |             | 3.977 | .264  |
| Normal               | 7.84        |             |       |       |
| Minor damage         | 22.22       |             |       |       |
| Meniscal repair      | 12.50       |             |       |       |
| Partial meniscectomy | 21.05       |             |       |       |
| Medial meniscal damage |             |             | 5.692 | .128  |
| Normal               | 11.29       |             |       |       |
| Minor damage         | 14.29       |             |       |       |
| Meniscal repair      | 33.33       |             |       |       |
| Partial meniscectomy | 8.33        |             |       |       |

*Data are presented as mean ± SD or percentage. ACLR, anterior cruciate ligament reconstruction; ATTD, anterior tibial translation side-to-side difference; IKDC, International Knee Documentation Committee; PT, peak torque.*