Original Article

Postoperative Tunnel Widening, Elliptical Aperture Shape, and No Preservation of the Remnant Are Related to the Tendon Graft—Bone Tunnel Gap Formation at the Intra-Articular Aperture After Double-Bundle Anterior Cruciate Ligament Reconstruction

Ryo Kanto, M.D., Ph.D., Motoi Yamaguchi, M.D., Ph.D., Shinichi Yoshiya, M.D., Ph.D., Akio Matsumoto, M.D., Ph.D., Ken Sasaki, M.D., Ph.D., Shunichiro Kambara, M.D., Ph.D., Hiroshi Nakayama, M.D., Ph.D., and Toshiya Tachibana, M.D., Ph.D.

Purpose: To examine the bone—tendon healing at the posterolateral (PL) femoral tunnel aperture by second-look arthroscopy after double-bundle anterior cruciate ligament reconstruction (ACLR), and assess the risk factors for impaired healing at the tendon—bone interface. **Methods:** A consecutive series of knees undergoing primary double-bundle ACLR using hamstring tendon autografts were enrolled in the study. The exclusion criteria were as follows: previous knee surgeries, concomitant ligamentous and osseous procedures, and a lack of second-look arthroscopy or postoperative computed tomography data for the analysis. Cases in which a gap was identified between the graft and tunnel aperture during the second-look arthroscopic examination were classified as the gap formation (GF) group. A multivariate logistic regression analysis was performed to assess the relationship between the GF and variables that may determine prognosis. **Results:** A total of 54 knees that met the inclusion/exclusion criteria were included in the study. Second-look arthroscopy revealed the GF at the PL aperture in 22 of the 54 knees (40%). The time period from surgery to arthroscopy averaged 16 months. In the multivariate logistic regression analysis, the percentage tunnel widening at 1 year on computed tomography (odds ratio, 10.4; 95% confidence interval [CI] 1.56-69.2), ellipticity of the tunnel aperture (odds ratio, 3.57; 95% CI, 0.79-16.11), and no ACL remnant preservation (odds ratio, 5.99; 95% CI, 1.23-29.06) were identified as prognostic factors significantly related to graft—bone tunnel GF. **Conclusions:** Second-look arthroscopy revealed GF at the PL graft—bone tunnel interface in 40% of the knees after double-bundle ACLR. Incomplete healing of the interface, as evidenced by a graft—bone gap at the tunnel aperture, was associated with tunnel widening 1-year postsurgery, an elliptical aperture shape, and no preservation of the ACL remnant. **Level of Evidence:** III, retrospective case—control study.

Anterior cruciate ligament reconstruction (ACLR) using soft-tissue autograft is a procedure that has become more commonly performed in recent years. A potential shortcoming of this procedure, however, is that it does not reproduce the anatomical structure of the native anterior cruciate ligament (ACL) insertion site as the result of incomplete tendon graft—bone tunnel incorporation.[1] The tendon—bone healing

From the Department of Orthopaedic Surgery, Meiwa Hospital, Nishinomiya (R.K., M.Y., A.M.); Department of Orthopaedic Surgery, Hyogo Medical University, Nishinomiya (R.K., S.K., H.N., T.T.); Department of Orthopaedic Surgery, Nishinomiya Kaisei Hospital, Nishinomiya (S.Y.); and Department of Orthopaedic Surgery, Anshin Hospital, Kobe (K.S.), Hyogo, Japan.

The authors report that they have no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received September 25, 2022; accepted February 6, 2023.

Address correspondence to Ryo Kanto, M.D., Ph.D., Department of Orthopaedic Surgery, Hyogo Medical University, Nishinomiya, Hyogo, Japan. E-mail: ryokanto710@gmail.com

2666-061X/221217

https://doi.org/10.1016/j.asmr.2023.02.002

process of ACLR with soft-tissue grafts has been shown to be influenced by multiple factors, including tunnel placement,[2] graft and bone tunnel size matching, and graft-fixation methods.[3] Problems with these surgical factors may lead to micromotion and gaps at the interface between the graft and the bone tunnel, resulting in an influx of synovial fluid with high cytokine levels and consequent osteolysis and inhibition of tendon-to-bone healing.[4,5]

Although there have been a number of clinical studies addressing this issue, those studies have mostly focused on bone tunnel enlargement on computed tomography (CT) examination and its impact on clinical outcomes. Therefore, the status of tendon graft—bone tunnel healing at the intra-articular tunnel aperture has not been fully clarified from the perspective of reproducing normal ACL insertion. In this study, healing of the ACL graft attachment at the bone tunnel aperture was assessed by second-look arthroscopy. In our practice, a double-bundle ACLR using hamstring tendon grafts has been a principal technique. In this reconstructive method, there is concern that the interface may shift due to changes in graft length caused by postoperative knee motion, especially in the posterolateral (PL) bundle graft, and that tendon-to-bone fusion at the attachment site may not be achieved. In fact, our clinical experience has shown that incomplete tendon—bone healing with gap formation is most often identified at the femoral intraarticular aperture (IAA) of the PL graft on the second-look arthroscopy.

The purposes of this study were to examine the bone—tendon healing at the PL femoral tunnel aperture by second-look arthroscopy after double-bundle ACLR and to assess the risk factors for impaired healing at the tendon—bone interface. It was hypothesized that graft—bone tunnel gap at the IAA of the femoral PL tunnel would be observed on second-look arthroscopy at a substantial rate, and an overly elliptical IAA associated with initial graft-bone tunnel geometric mismatch would affect the tendon graft—bone tunnel healing.

Methods

Patient Selection

This study represents a retrospective review of consecutive patients who underwent ACLR at our hospital from April 2013 to April 2015. The inclusion criterion was primary double-bundle ACLR using autogenous semitendinosus tendon grafts, whereas the exclusion criteria were as follows: previous knee surgeries, concomitant ligamentous and osseous procedures, and a lack of second-look arthroscopy results or postoperative CT data for the analysis. Institutional review board approval was obtained for this study, and all patients provided written informed consent for the study. The ethics review board of Meiwa Hospital approved this study (No. 2020-13).

Surgical Procedures and Rehabilitation

All surgeries were performed with the patient under general anesthesia by 1 of the 3 senior authors (M.Y., A.M., and K.S.). Before the initial ACL reconstructive procedure, a thorough arthroscopic evaluation was performed. The morphology of the ruptured ACL remnant was evaluated for attachment site and continuity and classified into 4 types based on the remnant classification described by Crain et al.[6] The remnants were identified as Crain types 1, 2, and 3 were preserved in primary ACLR.

The autogenous semitendinosus tendon was harvested as graft material and prepared as double-stranded grafts for each of the anteromedial (AM) and PL grafts. The femoral AM tunnel was drilled using the outside-in technique, whereas the femoral PL tunnel was drilled with either the transportal inside-out or the outside-in technique, depending on surgeon preference and individual anatomy. Both the AM and PL femoral tunnels were placed behind the resident's ridge, just anterior to the posterior cartilage margin, whereas the PL tunnel aperture was placed at a more posterior (low) and distal (shallow) position in relation to the AM tunnel. The AM and PL tibial bone tunnels were drilled with an outside-in technique. The diameter of the bone tunnel was measured with a sizing tube and corresponded to match the graft diameter.

Graft fixation was achieved by ENDOBUTTON-CL (Smith & Nephew, Andover, MA) for the femur, whereas the tibial end of the graft construct was fixed to a screw post. During graft fixation, the knee was slightly flexed for the AM graft and fully extended for the PL graft with manual maximum tension applied to the graft during fixation.

After surgery, the operated knee was fixed in extension and immobilized with a brace to prevent weight-bearing for the first week in patients who underwent ACLR. Afterward, range-of-motion exercises and partial weight-bearing were initiated and gradually increased to full weight-bearing by 3 weeks' postsurgery. In patients who underwent ACLR with meniscus repair, partial weight-bearing and range-of-motion exercises were permitted at 2 weeks after surgery with full weight-bearing at 4 weeks after surgery. Running was initiated at 4 months. From 8 months on, patients were permitted to return to full athletic activity once the satisfactory anterior and rotational stability, muscle strength, and neuromuscular coordination were confirmed.

Clinical Assessment

A comprehensive clinical evaluation including physical examination and assessment of clinical outcomes

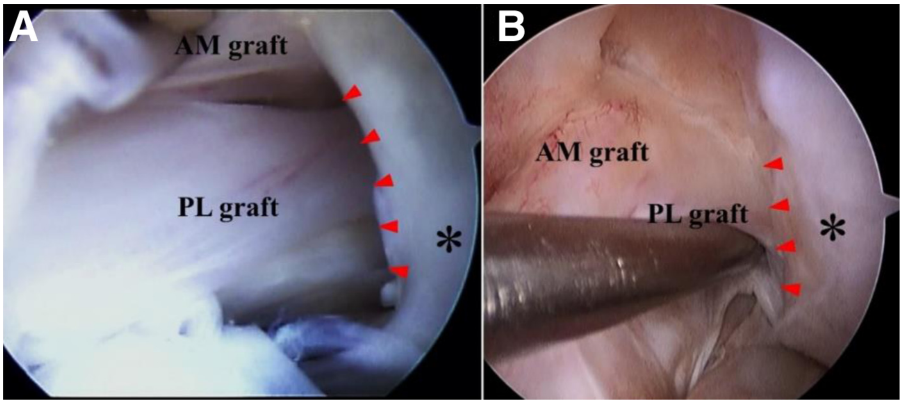

Fig 1. During second-look arthroscopy, the tendon graft–bone tunnel interface at the PL femoral IAA is carefully viewed from the anteromedial portal in the figure-of-4 position (left knee). Observation for any gaps was conducted via probing, and subjects were assigned to either the GF or NGF group according to arthroscopic findings. (A) A representative case from the GF group. The PL graft–bone tunnel gap at the IAA (red arrowheads) and synovial fluid inflow at the PL graft–bone tunnel interface are observed. (B) A representative case from the NGF group shows good synovial coverage with continuity at the PL graft-bone tunnel IAA (red arrowheads). *The lateral femoral condyle. (AM, anteromedial; GF, gap formation; IAA, intra-articular aperture; NGF, no gap formation; PL, posterolateral.)

using the Lysholm score and the Tegner activity scale was conducted in all cases 1 year after ACLR. Static anterior stability was quantitatively evaluated with a KT-1000 arthrometer immediately before the second-look arthroscopy under general anesthesia (based on side-to-side difference at manual maximum stress), and dynamic stability was evaluated with the pivot-shift test under general anesthesia just before the second-look arthroscopy. The KT-1000 results were assessed as a continuous variable, whereas the pivot-shift test results were recorded as a binary variable (+ or −).

Second-Look Arthroscopic Evaluation

Indications for second-look arthroscopy were as follows: (1) patients who consented to second-look arthroscopy and opted for tibial post screw removal and (2) patients with suspected intra-articular treatable lesions such as meniscal and cyclops lesions. Hardware removal was performed at least 1 year after surgery based on the patient's decision. Those who had discomfort or pain at the screw head site preferred to have the screw removed. The surgeon who performed the initial ACLR procedure also conducted the second-look arthroscopic evaluation. To assess the tendon graft–bone tunnel gap at the PL aperture, the bone–tendon interface at the aperture was carefully visualized and probed from the AM portal with the leg in a figure-of-4 position to assess the presence of any gaps. Cases in which the probe could be easily inserted into the gap between the graft and bone tunnel were classified into the gap formation (GF) group (Fig 1A), and those in which the graft and IAA were continuous without a gap were assigned to the no gap formation (NGF) group (Fig 1B). Compared with the PL graft IAA, limited field of view during arthroscopic observation of the femoral AM graft attachment site in the proximal and posterior areas made accurate assessment difficult in many cases. In addition, the incidence of tunnel widening (TW) at the aperture has been reported to be greater in the PL femoral tunnel than in the AM aperture.[7,8] Therefore, the observation in this study was limited to the femoral PL IAA in this study.

Postoperative CT Evaluation

With each patient's informed consent, CT examinations were performed 1 week and 1 year after ACLR to evaluate the geometry of the bone tunnel. A 256-slice multidetector CT scanner (Brilliance iCT; Philips Healthcare, Amsterdam, the Netherlands) with the slice thickness set at 0.7 mm was used for all examined knees. The knees were placed in full extension during image acquisition. After extracting the Digital Imaging and Communications in Medicine data from the picture archiving and communication system software, we exported the image data to the ZioTerm2009 imaging software (Ziosoft Inc., Tokyo, Japan). Quantitative geometric assessment was performed using the ZioTerm2009 imaging software in accordance with the method used in previous study.[9]

To measure the longer axis length of the PL IAA, the plane parallel to the inner wall surface of the lateral femoral condyle was established as a reference on the 3-dimensional (3D)-reconstructed images (Fig 2A). Then, an image was generated at the PL IAA level and the longer axis length of the elliptical aperture was measured using that image (Fig 2B). In the assessment of the graft bending angle, the geometric center of the PL femoral and tibial IAAs was first located on the 3D

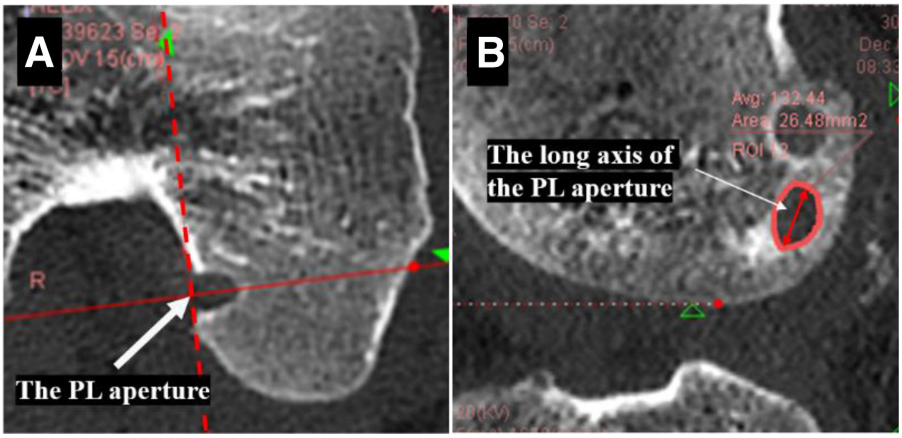

Fig 2. Measurement of the long-axis length of the PL aperture on postoperative computed tomography imaging (left knee). (A) The plane parallel to the inner wall surface of the lateral femoral condyle shown on the 3-dimensional—reconstructed images is set as a reference (red dashed line). (B) The length of the PL long axis (double-headed red arrow) is measured on the section image made at the bone tunnel aperture level. (PL, posterolateral.)

image to determine the trajectory of the intraarticular graft. The long axis along the bone tunnel was determined by connecting the geometric centers of the intra- and extra-articular tunnel apertures. The angle between the line of the intra-articular PL graft and the PL femoral bone tunnel was then measured on the 3D geometry (Fig 3). The position of the femoral PL tunnel was quantitatively evaluated using the method described by Bernard et al.[10] A coordinate system was established on the inner wall of the lateral femoral condyle, and the location of the IAA center was defined by the percentage values with respect to the total length for each of the shallow/deep and high/low coordinate axes (Fig 4).

Statistical Analysis

Statistical analysis of potential risk factors for GF was initially performed with a univariate analysis. In the first part of the analysis, differences between the GF and the NGF groups were statistically analyzed for the following 12 independent variables: age, sex, body mass index, pivot shift test result, Tegner activity scale, KT-1000 side-to-side difference, TW percentage (ie, the percentage increase in long axis diameter of the PL aperture from 1 week to 1 year after ACLR), graft bending angle at 1 week, tunnel ellipticity (TE, ie, the long-axis length of the PL aperture/intraoperative drill diameter ratio) at 1 week, ACL remnant preservation, concomitant meniscus repair, and femoral PL tunnel position at 1 week. The Fisher exact test was used to compare categorical variables, and the Mann—Whitney *U* test was used to compare continuous variables. The variables that showed a value of $P < .1$ in the univariate analysis were further analyzed in a multivariate logistic regression analysis.

Based on the analysis, the statistical results are indicated by odds ratios, 95% confidence intervals (CIs), and *P* values. All *P* values were 2-sided, and $P < .05$ was considered statistically significant. In addition, receiver operating characteristic curve analysis was performed for those factors that proved to be significantly influential in determining sensitivity, specificity, and optimal cutoff values. Statistical analyses were performed using SPSS (version 19, IBM Corp., Armonk, NY) software.

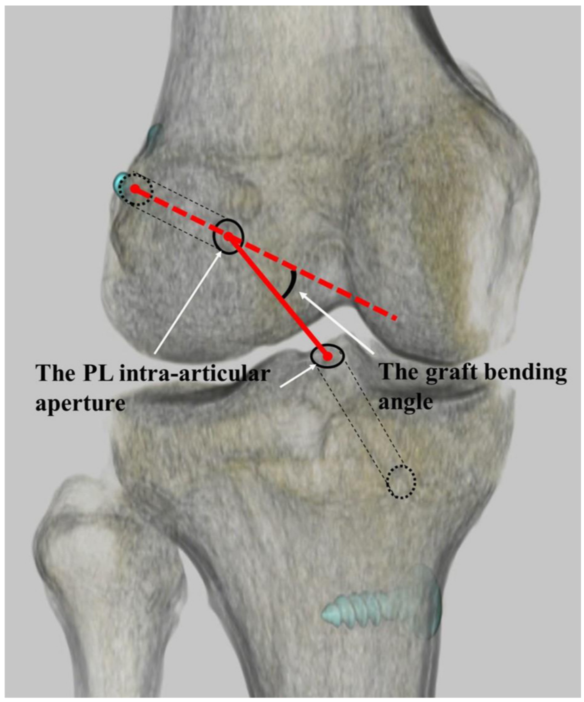

Fig 3. The geometric centers of the PL femoral and tibial IAAs were located on the 3D images and used to determine the trajectory of the intra-articular graft (red line) (left knee). The long axis along the bone tunnel was determined by connecting the geometric centers of the intra- and extra-articular tunnel apertures (red dashed line). Then, the angle formed between the intra-articular PL graft and PL femoral bone tunnel was measured as the PL graft bending angle on 3D geometry. (3D, 3-dimensional; IAA, intra-articular aperture; PL, posterolateral.)

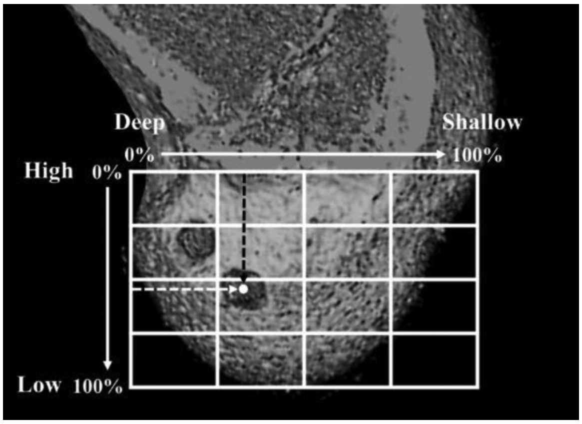

Fig 4. Measurement of the PL femoral tunnel position using the quadrant method. A coordinate system was established on the inner wall of the lateral femoral condyle as described by Bernard et al.,[8] and the location of the IAA center was defined by the percentage values with respect to the total length for each of the shallow/deep and high/low coordinate axes. (IAA, intra-articular aperture; PL, posterolateral.)

Regarding sample size power calculation, this study of 22 patients in the GF group and 32 patients in the NGF group was calculated to have an adequate power $1 - \beta$ of 0.81 with an α of 0.05, using free statistical power analysis software (G*Power, version 3.1.9.2; Franz Faul, Universität Kiel, Kiel, Germany).

Intra- and interobserver reliability of the CT measurements for geometric parameters was determined by calculating the intraclass correlation coefficient. The intraclass correlation coefficients ranged from 0.921 to 0.996, showing excellent reliability.

Results

Of the 234 patients who underwent double-bundle ACLR during the study period, 180 patients were excluded for meeting the following exclusion criteria: those who had previous knee surgeries (8), concomitant ligamentous and osseous procedures (4), and those who lacked second-look arthroscopic results (106) or postoperative CT data (62) available for the analysis. As a result, 54 patients met the inclusion/exclusion criteria and remained eligible for the study analysis. Second-look arthroscopy was performed concomitantly with hardware removal in 48 knees and indicated for intra-articular treatable lesion in 6 knees. The mean follow-up period in this study population was 16 months (range, 12-24 months). There was no significant difference between the 2 groups in the mean Lysholm scores 1 year after ACLR (GF group 95.4 ± 3.6 vs NGF group 94.5 ± 4.5, $P = .62$).

Second-Look Arthroscopic and Postoperative CT Evaluation

The time period from surgery to second-look arthroscopy averaged 16 months (range, 12-24 months), and tendon—bone tunnel GF at the PL aperture was identified in 22 of the 54 knees (40%). CT evaluation at 1 year after ACLR showed that the long-axis diameter of the PL tunnel IAA had enlarged by 43.3 ± 20.9% (2.5 ± 1.7 mm) compared with the results at 1 week. The mean TE values at 1-week and 1-year post-ACLR were 1.18 and 1.69, respectively.

Assessment of Prognostic Factors and Cut-Off Values

In the multivariate logistic regression analysis, the percentage TW (odds ratio, 10.4; 95% CI, 1.56-69.2), the TE at 1 week after ACLR (odds ratio, 3.57; 95% CI 0.79-16.11), and no ACL remnant preservation (odds ratio, 5.99; 95% CI, 1.23-29.06) were identified as prognostic factors that were significantly related to graft—bone tunnel GF (Tables 1 and 2). The receiver operating characteristic curve analysis revealed that the AUC size of the PL TW percentage was 0.747 (95% CI 0.59-0.91), and the optimal cutoff value was 1.22. The AUC size of the PL TE was 0.766 (95% CI 0.57-0.96), and the optimal cutoff value was 1.46 (Fig 5).

Discussion

The most important finding in this study was that the graft—bone tunnel GF at the femoral PL tunnel IAA was observed in 40% of the study subjects. Furthermore, logistic regression analysis showed that the postoperative TW percentage, the TE at 1 week postsurgery, and status of ACL remnant preservation were the factors that were significantly related to incomplete healing and a gap at the femoral PL tunnel IAA. To our knowledge, no studies have reported the healing status at the IAA assessed by second-look arthroscopy or the relationship between clinical and radiologic factors and graft—bone tunnel GF. Postoperative graft—bone tunnel GF leads to micromotion at the interface between the graft and the bone tunnel, potentially impairing tendon-to-bone healing.[4,5] Therefore, prevention of the GF at the interface between the graft and the bone tunnel should be an issue of consideration in primary ACLR.

Among the factors influencing graft—bone fusion at the femoral PL IAA, this study showed postoperative TW to be most closely related to GF at the interface with an odds ratio of 10.4 and the cutoff value of 22%. The close relationship between postoperative TW and GF shown in this study suggests that these 2 phenomena

Table 1. Univariate Analysis of Demographic/Clinical Factors and Geometric Parameters of the Bone Tunnel Evaluated on Postoperative CT Images to Compare the GF and NGF Groups

Variable	GF group (n=22)	NGF group (n=32)	*P*-value
Age	24.6 ± 12.6	22.1 ± 8.4	0.55
Sex (Male / Female)	7 / 15	10 / 22	1.00
Body mass index (m^2/kg)	22.8 ± 3.3	22.7 ± 3.5	0.82
Pivot shift test, positive	6 (27.3%)	6 (18.8%)	0.52
Tegner activity scale	6.6 ± 1.1	6.3 ± 1.2	0.46
KT-1000 side to side difference (mm)	0.8 ± 1.2	0.6 ± 1.8	0.99
The percentage PL TW between one week and one year after ACLR	59.3 ± 18.5	38.6 ± 19.1	**0.024***
The PL graft bending angle at one week after ACLR (°)	62.4 ± 5.9	65.9 ± 9.3	0.14
The PL TE at one week after ACLR	1.3 ± 0.1	1.1 ± 0.1	**0.013***
No ACL remnant	9 (40.9%)	4 (12.5%)	**0.024***
Meniscus repair	10 (45.5%)	11 (34.4%)	0.57
Femoral PL tunnel position at one week after ACLR (%)			
Deep/Shallow	31.5 ± 5.0	29.3 ± 5.4	0.19
High/Low	55.4 ± 7.6	57.6 ± 8.8	0.42

NOTE. Results are expressed as means ± standard deviation.

ACLR, anterior cruciate ligament reconstruction; GF, gap formation; NGF, no gap formation; PL, posterolateral; TE, tunnel ellipticity; TW, tunnel widening.

*Difference with $P < .1$ in the univariate analysis.

have common background and etiology. As for the etiologies of TW, both mechanical and biological factors have been described in the previous relevant papers. Mechanical factors include nonanatomic tunnel placement,[11] micromotion of the graft at the tunnel aperture, increased stress at the graft—tunnel interface, and aggressive rehabilitation.[7,12,13] From a biological standpoint, synovial fluid—derived cytokines and inflammatory mediators, bony quality, and cell necrosis induced by drilling[14,15] have been listed as causative factors. Preventing TW by taking those factors into account may also reduce the occurrence of GF.

Another significant factor related to GF in this study was TE, with an odds ratio of 3.57. This finding suggests that a tunnel aperture with too much of an elliptical shape can create a gap between the graft and bone tunnel, allowing movement and synovial fluid influx at the graft—bone interface and preventing the gap from being filled with healing tissue. L'Insalata et al[16] described the importance of fully accommodating the graft at the tunnel IAA for the prevention of TW, based on the results of a clinical comparative study. In a prospective studym Hwang et al[17] compared changes in femoral tunnel volume between hamstring grafts inserted with the press-fit technique (0.5 mm underdrilled tunnels) and a conventional femoral technique (same size graft and tunnel) during CT examination 1-year post-ACLR, and reported a greater predominance of TW at the IAA in the latter group. These studies indicate that a mismatch between the area of the graft and bone tunnel (greater IAA area compared with that of the graft cross section) may affect the healing at the graft insertion site. Considering this etiologic sequence, it can be beneficial to create a round-shape IAA that matches the graft and bone tunnel area at the IAA to reduce the graft-bone tunnel gap.

The third factor in this study showing significant influence on tendon—bone healing at the IAA was the status of ACL remnant preservation at the ACLR. Remnant preserving ACLR has been performed for various purposes, such as preservation of mechanoreceptors, acceleration of graft revascularization/ligamentization, reduction of TW, and improvement in postoperative knee stability.[18-20] This study supports the potential benefits of remnant preserving ACLR by promoting tissue healing at the PL femoral tunnel IAA. Improved healing at the graft—bone tunnel in remnant

Table 2. Multivariate Regression Analysis of Factors Influencing Postoperative PL Graft—Bone Tunnel GF

Variable	Odds ratio	95% CI	*P*-value
The percentage PL TW between one week and one year after ACLR	10.4	1.56-69.2	**0.016***
The PL TE at one week after ACLR	3.57	0.79-16.11	**0.044***
No ACL remnant	5.99	1.23-29.06	**0.026***

ACLR, anterior cruciate ligament reconstruction; CI, confidence interval; GF, gap formation; PL, posterolateral; TE, tunnel ellipticity; TW, tunnel widening.

*Statistically significant difference ($P < .05$) in the multivariable regression analysis.

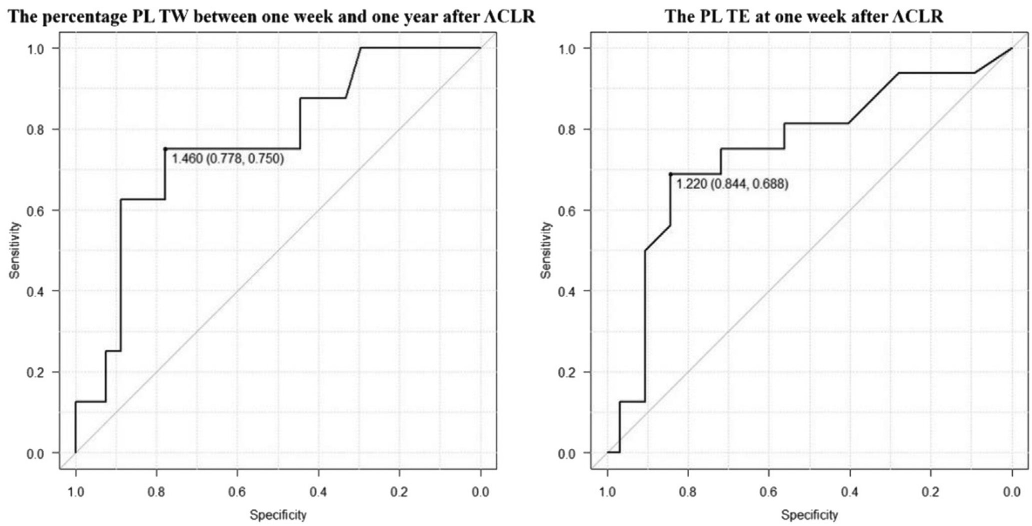

Fig 5. ROC curves of the percentage PL TW (AUC, 0.747; sensitivity, 84%; specificity, 69%; cutoff value, 1.22) and the PL TE (AUC, 0.766; sensitivity, 78%; specificity, 75%; cutoff value, 1.46). (AUC, area under the curve; PL, posterolateral; ROC, receiver operating characteristic; TE, tunnel ellipticity; TW, tunnel widening.)

preserving ACLR may be achieved by covering the tunnel aperture with tissue to prevent an influx of inflammatory cytokines from entering the bone tunnel.[21]

Other reported surgical factors include a steep graft bending angle and bone tunnel malposition that can affect fusion of the graft–bone interface at the IAA.[9,22] In this study, however, those factors were not shown to be significantly related to GF after surgery. The analytical results of each study are variable due to differences in patient and clinical characteristics between studies.

The results of this study showed no significant difference in clinical outcomes between knees with or without a graft-bone tunnel GF upon assessment 1 year after ACLR. Previous studies examining the effects of TW on clinical outcomes and knee stability after double-bundle ACLR have reported variable results.[16] Further study with a larger patient population and greater follow-up rate may be needed to clarify the relationship between healing status at the graft attachment site and the outcome of double-bundle ACLR.

Limitations

There were several limitations included in the design and contents of this study. First, this study examined only PL femoral tunnel apertures. Second, the healing statuses at the other three IAAs were not included in the analysis. Third, the minimum 1-year follow-up period was too short, since it is generally understood that TW mostly occurs in the first year after surgery and then gradually plateaus.[23-25] Fourth, the results presented in this study represent only 23% of the total population who underwent primary ACLR due to the lack of second-look arthroscopic results or postoperative CT data available for analysis. This shortcoming is related to the possibility of selection bias. In addition, the data analysis for the mixed groups of patients who underwent second look arthroscopy both with and without symptoms can be another source of bias. Finally, 3 surgeons performed ACLR using either a transportal or outside-in femoral drilling technique, and the second-look arthroscopic evaluation was conducted by the surgeon who performed the ACLR. This issue may result in surgical performance and assessment biases.

Conclusions

Second-look arthroscopy revealed the GF at the PL graft–bone tunnel interface in 40% of the knees after double-bundle ACLR. Incomplete healing of the interface, as evidenced by graft-bone gap at the tunnel aperture, was associated with TW 1-year postsurgery, an elliptical aperture shape, and no preservation of the ACL remnant.

Acknowledgments

The authors acknowledge Rebecca Imaizumi for her assistance in editing the English of this article.

References

1. Nakase J, Kitaoka K, Toratani T, Kosaka M, Ohashi Y, Tsuchiya H. Grafted tendon healing in femoral and tibial tunnels after anterior cruciate ligament reconstruction. *J Orthop Surg (Hong Kong)* 2014;22:65-69.
2. Ekdahl M, Nozaki M, Ferretti M, Tsai A, Smolinski P, Fu FH. The effect of tunnel placement on bone–tendon healing in anterior cruciate ligament reconstruction in a goat model. *Am J Sports Med* 2009;37:1522-1530.

3. Zantop T, Weimann A, Wolle K, Musahl V, Langer M, Petersen W. Initial and 6 weeks postoperative structural properties of soft tissue anterior cruciate ligament reconstructions with cross-pin or interference screw fixation: An in vivo study in sheep. *Arthroscopy* 2007;23:14-20.
4. Wilson T, Kantaras A, Atay A, Johnson D. Tunnel enlargement after anterior cruciate ligament surgery. *Am J Sports Med* 2004;32:543-549.
5. Sun L, Zhou X, Wu B, Tian M. Inhibitory effect of synovial fluid on tendon-to-bone healing: An experimental study in rabbits. *Arthroscopy* 2012;28:1297-1305.
6. Crain EH, Fithian DC, Paxton EW, Luetzow WF. Variation in anterior cruciate ligament scar pattern: Does the scar pattern affect anterior laxity in anterior cruciate ligament-deficient knees? *Arthroscopy* 2005;21:19-24.
7. Taketomi S, Inui H, Sanada T, Yamagami R, Tanaka S, Nakagawa T. Eccentric femoral tunnel widening in anatomic anterior cruciate ligament reconstruction. *Arthroscopy* 2014;30:701-709.
8. Siebold R. Observations on bone tunnel enlargement after double-bundle anterior cruciate ligament reconstruction. *Arthroscopy* 2007;23:291-298.
9. Kambara S, Nakayama H, Yamaguchi M, et al. Comparison of transportal and outside-in techniques for posterolateral femoral tunnel drilling in double-bundle ACL reconstruction—three-dimensional CT analysis of bone tunnel geometry. *J Orthop Sci* 2017;22:481-487.
10. Bernard M, Hertel P, Hornung H, Cierpinski T. Femoral insertion of the ACL. Radiographic quadrant method. *Am J Knee Surg* 1997;10:14-21. discussion 21-22.
11. Iorio R, Vadala A, Argento G, Di Sanzo V, Ferretti A. Bone tunnel enlargement after ACL reconstruction using autologous hamstring tendons: A CT study. *Int Orthop* 2007;31:49-55.
12. Bhullar R, Habib A, Zhang K, et al. Tunnel osteolysis post-ACL reconstruction: A systematic review examining select diagnostic modalities, treatment options and rehabilitation protocols. *Knee Surg Sports Traumatol Arthrosc* 2019;27: 524-533.
13. Höher J, Möller H, Fu F. Bone tunnel enlargement after anterior cruciate ligament reconstruction: Fact or fiction? *Knee Surg Sports Traumatol Arthrosc* 1998;6:231-240.
14. Darabos N, Haspl M, Moser C, Darabos A, Bartolek D, Groenemeyer D. Intraarticular application of autologous conditioned serum (ACS) reduces bone tunnel widening after ACL reconstructive surgery in a randomized controlled trial. *Knee Surg Sports Traumatol Arthrosc* 2011;19:S36-S46 (suppl 1).
15. Iorio R, Vadala A, Di Vavo I, et al. Tunnel enlargement after anterior cruciate ligament reconstruction in patients with post-operative septic arthritis. *Knee Surg Sports Traumatol Arthrosc* 2008;16:921-927.
16. L'Insalata J, Klatt B, Fu F, Harner C. Tunnel expansion following anterior cruciate ligament reconstruction: A comparison of hamstring and patellar tendon autografts. *Knee Surg Sports Traumatol Arthrosc* 1997;5:234-238.
17. Hwang DH, Shetty GM, Kim JI, et al. Does press-fit technique reduce tunnel volume enlargement after anterior cruciate ligament reconstruction with autologous hamstring tendons? A prospective randomized computed tomography study. *Arthroscopy* 2013;29:83-88.
18. Franciozi CE, Minami FK, Ambra LF, Galvao P, Schumacher FC, Kubota MS. Remnant preserving ACL reconstruction with a functional remnant is related to improved laxity but not to improved clinical outcomes in comparison to a nonfunctional remnant. *Knee Surg Sports Traumatol Arthrosc* 2022;30:1543-1551.
19. Okutan AE, Kalkisim M, Gurun E, Ayas MS, Aynaci O. Tibial slope, remnant preservation, and graft size are the most important factors affecting graft healing after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2022;30:1584-1593.
20. Takahashi T, Kondo E, Yasuda K, et al. Effects of remnant tissue preservation on the tendon graft in anterior cruciate ligament reconstruction: A biomechanical and histological study. *Am J Sports Med* 2016;44:1708-1716.
21. Zhang Q, Zhang S, Cao X, Liu L, Liu Y, Li R. The effect of remnant preservation on tibial tunnel enlargement in ACL reconstruction with hamstring autograft: A prospective randomized controlled trial. *Knee Surg Sports Traumatol Arthrosc* 2014;22:166-173.
22. Yanagisawa S, Kimura M, Hagiwara K, et al. A steep coronal graft bending angle is associated with bone tunnel enlargement of the posterolateral bundle after anterior cruciate ligament reconstruction. *J Orthop Surg (Hong Kong)* 2020;28:2309499019888811.
23. Weber AE, Delos D, Oltean HN, et al. Tibial and femoral tunnel changes after ACL reconstruction: A prospective 2-year longitudinal MRI study. *Am J Sports Med* 2015;43: 1147-1156.
24. Zhang S, Liu S, Yang L, Chen S, Chen S, Chen J. Morphological changes of the femoral tunnel and their correlation with hamstring tendon autograft maturation up to 2 years after anterior cruciate ligament reconstruction using femoral cortical suspension. *Am J Sports Med* 2020;48:554-564.
25. Fink C, Zapp M, Benedetto KP, Hackl W, Hoser C, Rieger M. Tibial tunnel enlargement following anterior cruciate ligament reconstruction with patellar tendon autograft. *Arthroscopy* 2001;17:138-143.