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Clinical outcome of a new remnant augmentation technique with anatomical double-bundle anterior cruciate ligament reconstruction: Comparison among remnant preservation, resection, and absent groups

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ABSTRACT

Purpose: The aim of this study was to verify the effects of a new remnant augmentation technique with anatomical double-bundle anterior cruciate ligament (ACL) reconstruction for postoperative clinical scores, anterior stability and frequency of complications compared to remnant removal and cases with remnant defects.

Methods: The 105 patients who underwent anatomical double-bundle ACL reconstruction were divided into three groups. If the remnant was a Crain I-III type, remnant-preserving bone tunnel creation was attempted. After the creation of the bone tunnel, good continuity was maintained in 34 patients (preserved group). Due to lost continuity, the remnant was resected in 26 patients (resected group). No identifiable remnant continuity remained (Crain IV) in 45 patients (absent group). The Lysholm knee score, Tegner activity scale, International Knee Documentation Committee (IKDC) subjective score, anterior stability measured using the KT-1000 arthrometer at 2 years postoperatively, and frequency of complications were compared among the three groups. Univariate and multiple linear regression analysis were performed to clarify the factors affecting postoperative anterior stability.

Results: The Lysholm knee score, Tegner activity scale, IKDC subjective score, and frequency of complications were not significantly different among the groups. The mean side-to-side difference of anterior stability was significantly better in the preserved group (0.3 ± 1.6 mm) compared to the resected group (1.6 ± 2.3 mm, $p = 0.003$) and absent group (1.6 mm ± 1.7, $p = 0.009$). The multiple linear regression analysis showed remnant preservation significantly related to postoperative anterior stability.

Conclusion: Although there were no differences in clinical scores, the ACL reconstruction with new preservation technique showed good anterior stability and no difference in the frequency of complications.

Introduction

Anterior cruciate ligament (ACL) reconstruction is one of the most common orthopaedic procedures for ACL rupture.[1] The procedure is useful for obtaining knee stability by stabilizing the anterior laxity of the knee joint due to ACL rupture and has been reported with good clinical results.[2] On the other hand, it has been reported that a certain percentage of cases remain with post-operative instability.[3] There are also reports that instability remains a risk for knee osteoarthritis and meniscal injury,[4,5] and there may still be a need for improvement in ACL reconstruction in order to obtain more consistent postoperative results.

In recent years, the remnant-preserving technique has been reported as an approach to improve postoperative results. The

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preservation of remnant tissues has been reported to enhance early revascularization and promote ligamentization,[6] improve the sense of joint position by preserving mechanoreceptors in tissues,[7] and prevent the enlargement of bone tunnels.[8] However, the results for anterior stability have been inconsistent, with some reports suggesting that preservation of the remnant improves anterior stability,[9,10] but others suggesting no improvement.[11–13] Although the methods for remnant preservation currently vary across studies, most are reconstructed by passing the reconstructed ligament "through" the remnants.[8–13] This procedure is difficult to perform and is prone to cause damage in the process of tunnel drilling and passing the ligament through the remnant. Depending on the condition of the remnant, the degree of coverage is likely to be very limited. Moreover, there have been reports in the literature that postoperative cyclops syndrome occurs more frequently than remnant resected methods.[14]

Crain et al.[15] classified the ACL remnants into four types, of which some contribute to the anterior stability in ACL injuries of the knee. With a focus on these residual mechanical properties of the remnant, a new anatomical ACL double-bundle reconstruction technique was reported which emphasized the preservation of continuity without damaging the remnant during the reconstruction process and the augmentation of the reconstructed graft using the residual remnant.[16] This method is novel in that the AM bundle is placed anterior to the remnant and the PL bundle is placed posterior to the remnant so that the bone tunnel can be created in an anatomical position without damaging the continuity of the remnant, whereas the graft is passed through the remnant in conventional methods. However, there are no studies that verify the effects of new remnant-preserving method that differ from conventional methods, how this affects the clinical outcome and postoperative anterior stability after ACL reconstruction, and whether there is a difference in the frequency of complications including cyclops syndrome. The purpose of this study was to verify the effects of anatomical remnant-preserving double-bundle ACL reconstruction with a remnant augmentation technique that focus on remnant continuity for postoperative clinical scores, anterior stability, and frequency of complications compared to remnant removal and cases with remnant defects. Our hypothesis is that this new ACL reconstruction technique using the remnant for structural augmentation is superior in postoperative clinical results and anterior stability compared to the conventional method with remnant resection, and that there is no difference in frequency of complications.

Materials and methods

Patient selection

This is a retrospective study. From 2012 May to 2017 April, patients who underwent double-bundle ACL reconstruction for treating ACL ruptures by a single surgeon (K.T.) were included. The exclusion criteria were (1) ACL reconstruction performed by other surgeons, (2) revision cases, (3) bilateral injuries, (4) history of surgery either in the contralateral or ipsilateral knee, (5) multiple ligament injuries, (6) ACL reconstruction with bone-tendon-bone (BTB) graft, and (7) selective single bundle ACL reconstruction for partial bundle ruptures of ACL. This study was approved by our institutional research ethics committee. Informed consent was obtained in the form of an opt-out on our hospital web-site.

Patients were divided into a preserved group, resected group, and absent group according to the procedure performed (Fig. 1). If the remnant was a Crain I-III type, remnant-preserving bone tunnel creation was attempted. After the creation of the bone tunnel in the preserved group, exhibited adequate thickness, firmly adhered to the femoral side or posterior cruciate ligament (PCL) according to visualization from probing, and retained more than 50% continuity under macroscopic observation (Fig. 2). In the resected group, the continuity was lost in the process of creating bone tunnels and the remnant was removed and ACL reconstruction was performed. When the remnant was a Crain type IV that was only observed in the tibial attachment with no continuity in the PCL or femur, the remnant was removed and ACL reconstruction was performed, which was designated as the absent group. In the resected and absent groups, all remaining remnants were resected and ACL reconstruction was performed.

Surgical technique

Preparation, graft harvest, arthroscopic portal formation, and examination

Surgery was performed based on the method described by Tensho et al.[16] The patient was placed in the supine position, and the affected limb was flexed 90° at the knee joint. In preparing the graft tendon, the ipsilateral semitendinosus tendon and, in some cases, the gracilis tendon were double- or quadruple-bundled. The cross-sectional area at the centre of the graft tendon was measured using a custom-made area micrometre (Meira Co., Nagoya, Japan).[17] Subsequently, the anterior medial and anterior lateral portals were created, and the joint was observed intraarticularly to confirm the presence or absence of meniscal and cartilage damage and the morphology of the remnant. If meniscal injuries were present, meniscal sutures or partial resection were performed prior to ACL reconstruction. The morphology of the remnant was arthroscopically probed to evaluate its attachment site and continuity, and was classified into four types based on the remnant classification described by Crain et al.[15]

Femoral and tibial tunnel formation

In the preserved group, the femoral tunnel was created by carefully cauterizing and removing the scar tissue on the femoral anatomical ACL attachment site, so as not to damage the femoral attachment site of the remnant. Because the remnant was not attached to the normal femoral attachments, it was possible to create a femoral tunnel in the anatomical position without damaging the femoral attachments of the remnant. An Anterolateral Entry Femoral Aimer (Smith & Nephew, Andover, MA) was used to insert guide pins for the anteromedial (AM) and posterolateral (PL) bundles by the outside-in method. After confirming the position of the guide pins, drilling was performed using a drill of equal size to the graft. The bone tunnel on the tibial side was constructed within the ACL footprint according to a method utilizing anatomical/bony landmarks.[18–20] This method uses a quadrilateral surrounded by four landmarks (medial intercondylar ridge, anterior border of medial and lateral intercondylar tubercles, and anterior horn of the lateral meniscus, Parsons' knob) to construct two bone tunnels. For the guide pin of the AM bundle, the remnant was split at the anterior border of the remnant attachment site in the direction of the fibre. An Acufex Director Drill Guide (Smith & Nephew, Andover, MA) was positioned and inserted at a distance that is one half the diameter of the AM graft tendon from the corner of the L-shaped ridge (a combination of the medial intercondylar ridge and Parsons' knob). The guide pin of the PL bundle was inserted anterior to the anterior border of the medial and lateral intercondylar tubercles with the guide placed 3–4 mm posterior to the AM guide pin so as to prevent coalition between the AM and PL tunnels and to be placed within the quadrilateral. When the guide pin was inserted in the proper position, the guide pin tip of the PL bundle could be seen just behind the remnant.

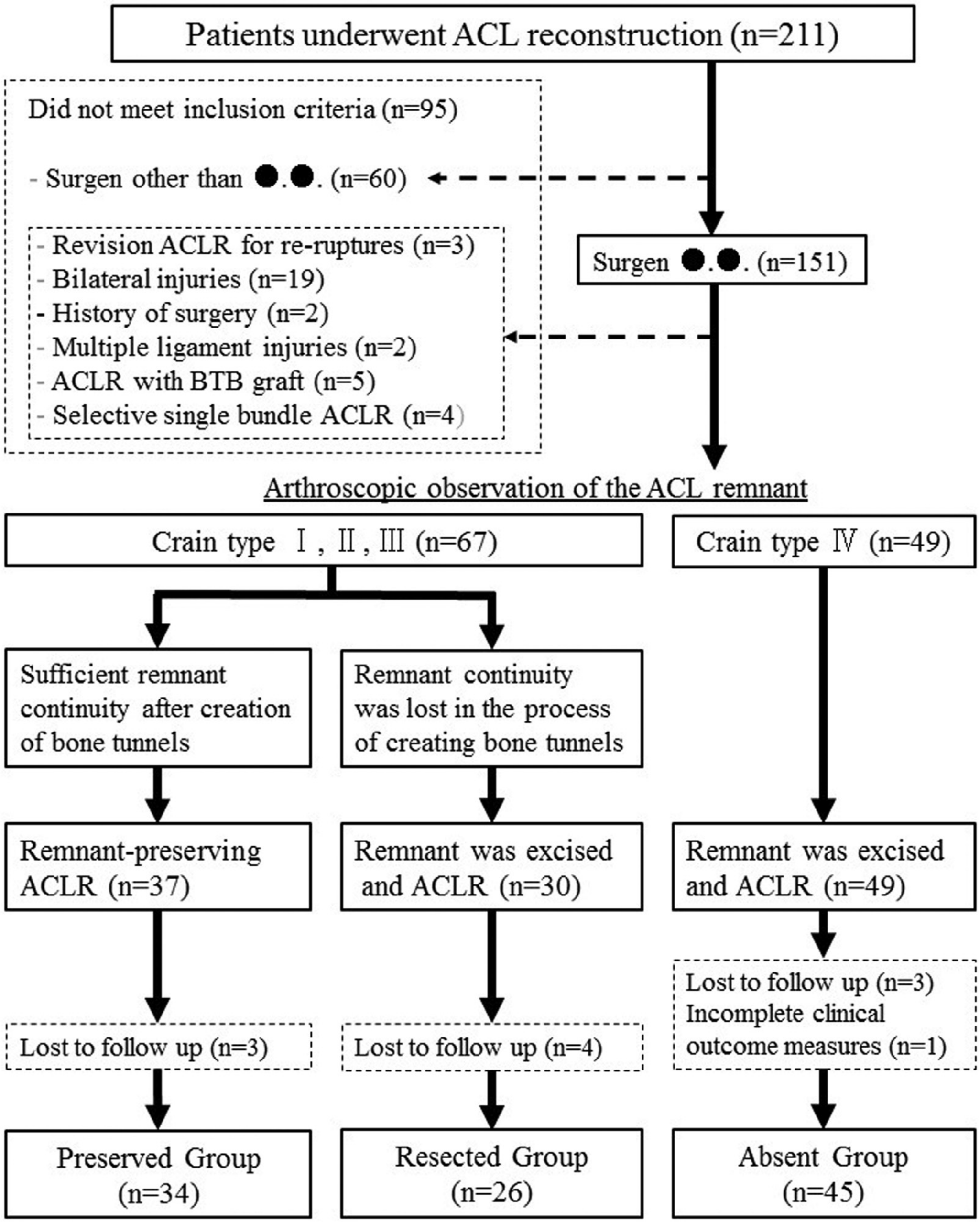

Fig. 1. Flow chart showing the criteria for patient enrolment and anatomical remnant-preserving double-bundle ACL reconstruction with a new remnant augmentation technique. ACL, anterior cruciate ligament; ACLR, ACL reconstruction; BTB, bone-tendon-bone.

After confirming the position of the guide pin, the tunnel was carefully drilled using a drill diameter that is 0.5 mm smaller than the graft size so as not to damage the remnant, and then gradually dilated to the same size using a dilator. In the resected group and absent group, bone tunnels were created using the same landmarks after resection of the remnant.

Since the direction of drilling and the direction of remnant travel are different, damage to the remnant substance is minimized even if bone tunnels are created within the normal tibial attachment.

Fixation of the hamstring graft

A guide suture was passed through the AM and PL bundles from the femoral tunnel to tibial tunnel. In order to avoid damaging the remnant in the preserved group as much as possible, guide sutures for the AM and PL bundles were passed through the anterior and posterior sides of the remnants, respectively, and the tendon grafts were positioned anterior and posterior to the remnant (Fig. 3). Subsequently, the tendon grafts were adjusted so that the proximal end and distal end of the grafts were inserted into the femur and tibia by 10–15 mm, respectively. For the fixation of the femoral side, an EndoButton (Smith & Nephew Endoscopy, Andover, Massachusetts) or TightRope RT (Arthrex Inc, Naples, FL) were used. For fixation of the tibial side, a Double Spike Plate (Meira Co., Nagoya, Aichi, Japan) was used. Using a tensioning boot system (Meira Co., Nagoya, Japan), each graft tendon was fixed by applying an initial tension of 10 N at 20° flexion. The knees were flexed and extended, and we confirmed arthroscopically that the graft and remnant did

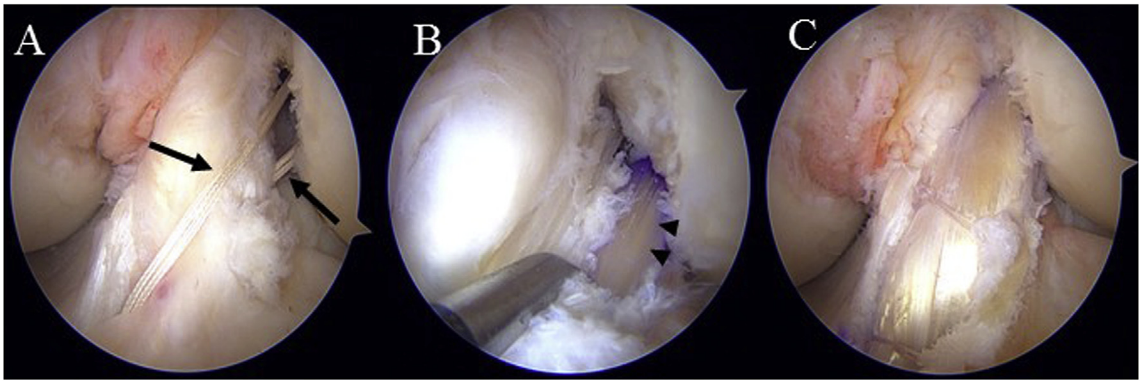

Fig. 2. Arthroscopic findings for the left knee of remnant-preserving anatomical double-bundle reconstruction (preserved group) using a remnant augmentation technique. (A) Arthroscopic findings of the left condyle. The ACL remnant is well preserved after creating the bone tunnel. A guide sutures (arrow) are passed anteroposteriorly to the remnant. (B) A PL graft (arrowhead) is passed posteriorly to the remnant. (C) After fixation of the graft, the AM graft is passed anteriorly to the remnant. AM, anteromedial; PL, posterolateral.

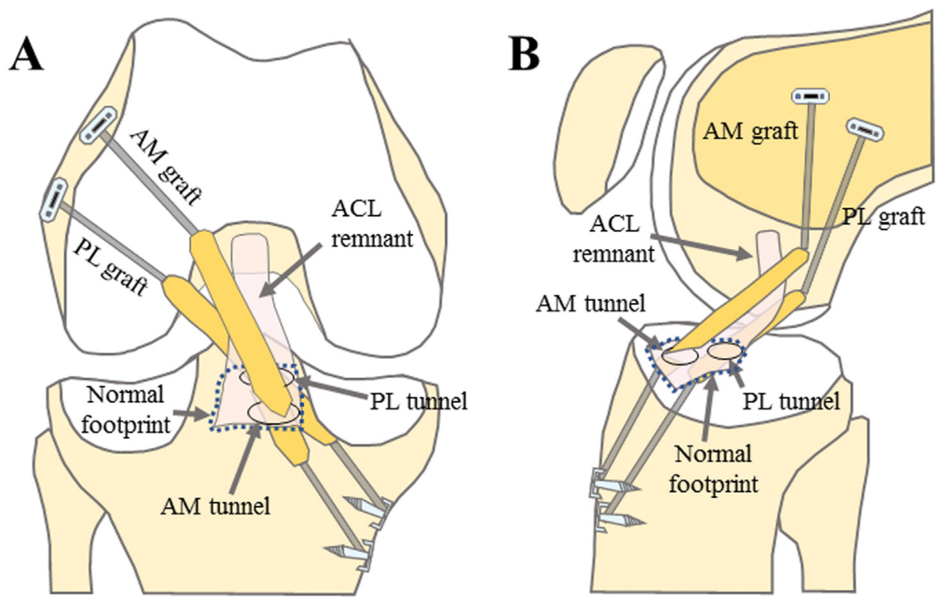

Fig. 3. Schematic of the right knee undergoing remnant-preserving anatomical double-bundle reconstruction (preserved group) using a remnant augmentation technique. (A) Anteroposterior view of a schematic diagram for the method that passes the graft laterally to the remnant. (B) Lateral view. The reconstructed ligament is anteroposteriorly positioned so as to "sandwich" the remnant. AM, anteromedial; PL, posterolateral.

not impinge on the femoral intercondylar notch and that there was no soft tissue in front of the graft that could cause a cyclops lesion.

Rehabilitation

All patients followed the same rehabilitation protocol, including combined surgery for meniscal tears. After splint fixation for 1 week after surgery, range of motion (ROM) training was permitted without any limitations. One-third partial load was initiated at 1 week after surgery, 1/2 partial weight bearing was allowed at 2 weeks, and full load was allowed 4 weeks. Running was allowed at 3 months postoperatively, and return to sports was permitted after 8–9 months.

Evaluation

A detailed medical history was obtained, including time from injury and history of lower limb surgery. For physical findings, the height, weight, body mass index (BMI), and the side-to-side difference in anterior stability measured by a KT-1000 arthrometer (MEDmetric® Corporation San Diego, CA) were evaluated. The Lysholm knee score was used for preoperative clinical evaluation, and the Tegner activity scale was used for sports activity level. The presence or absence of meniscal injuries prior to ACL reconstruction and patient history of related treatments such as resection and suturing were recorded. The morphology of the ACL remnant ligament was evaluated based on the remnant classification described by Crain et al.,[15] and its continuity was confirmed by probing. A coordinate system was mapped out on the medial wall of the lateral femoral condyle[21,22] and the tibial plateau surface[22] using 3D-CT images, and each bone tunnel was evaluated by expressing the centre position of the tunnel as a percentage.[22] Bone tunnel positions were measured by two orthopaedic surgeons (T.I. and K.T.) without their knowledge of patient medical records. At 2 years postoperatively, clinical outcomes were assessed using the Lysholm knee score and Tegner activity scale as metrics for objective assessment, and the International Knee Documentation Committee (IKDC) subjective score was used as a patient-oriented assessment.

Anterior stability was evaluated by applying an antegrade force of 133 N to the tibia at 30° flexion using a KT-1000 arthrometer and was measured by an experienced orthopaedic surgeon at 2 years postoperatively. All complications during follow-up were assessed including re-ruptures, necessity of arthroscopic debridement due to cyclops lesions, and infections. Those with cyclops lesions were identified as cases with pain during knee extension, restriction of extension, and an MRI showing a cyclops lesion anterior to the reconstructed ligament between the femoral condyle that were indicated for arthroscopic debridement surgery.

Statistical analysis

The statistical comparison among the three groups were evaluated by using analysis of variance (ANOVA) with a Bonferroni correction for multiple comparison and Fisher's exact test. Bone tunnel positions were measured by two orthopaedic surgeons, and the intra- and inter-rater reliability of measurements for bone tunnel positions were calculated by the mean value of intra-class correlation coefficients. A univariate linear analysis was performed with the postoperative KT-1000 side-to-side difference as the dependent variable, and age, sex, height, BMI, period from injury to surgery, preoperative KT-1000 side-to-side difference, complications from meniscal tear/repair/partial resection, and preservation of remnant as independent variables. Next, a multiple linear regression analysis was performed for those with a P-value of 0.2 or less in the single regression analysis. We performed a post hoc power analysis using G*Power version 3.1.9.4 (Franz Faul, Kiel, Germany). Based on a sample size of 105 knees, the power was 0.85 to detect a significant difference in the postoperative KT-1000 side-to-side difference between three groups using ANOVA, and the power was 0.87 to identify age, meniscal tear, preoperative KT-1000 side-to-side difference, and remnant preservation as an independent variable associated with the postoperative KT-1000 side-to-side difference in a multiple linear regression analysis. All statistical analyses were performed using the freeware EZR,[23] and a P value < 0.05 was considered statistically significant.

Results

Demographic data, intraoperative findings and treatments

Fig. 1 shows a patient flow chart for the three groups comprised of the 209 knees that underwent ACL reconstruction during the study period. There were 34 knees in the preserved group, 26 knees in the resected group, and 45 knees in the absent group. The average follow-up period was 29 months (range, 24–84 months). Table 1 shows the patient background, intraoperative findings, and treatments performed in each group (Table 1). There was no significant difference in demographic factors among the groups, with the exception of the age and remnant type. The age was significantly different between the preserved group and the absent group. The measured results of bone tunnel positions are shown in Table 2. There were no significant differences among the groups in terms of bone tunnel positions on both the femoral and tibial sides. The intra-rater reliability in measuring the bone tunnel position was 0.66–0.97, and the inter-rater reliability was 0.72–0.98.

Postoperative evaluation

Table 3 shows the postoperative Lysholm knee score, postoperative Tegner activity scale, postoperative IKDC, postoperative KT-1000 side-to-side difference, and postoperative complications. In terms of clinical scores, the postoperative Lysholm knee score, Tegner activity scale, and the postoperative IKDC subjective score were not significantly different among groups ($p = 0.41$, 0.58, and 0.34, respectively). The mean postoperative KT-1000 side-to-side difference was significantly lower in the preserved group (0.3 ± 1.6 mm) compared to the resected group (1.6 ± 2.3 mm, $p = 0.003$) and absent group (1.6 ± 1.7 mm, $p = 0.009$). There was no significant difference between the resected group and the absent group ($p = 1.0$). Regarding complications during follow-up, there was no significant difference in re-ruptures, cyclops debridement, and infections between groups ($p = 0.060$, 0.51, and >0.99 respectively).

In the univariate linear regression analysis, remnant preservation was significantly related to postoperative KT-1000 side-to-side difference ($p = 0.001$ Table 4). After the univariate linear regression analysis, age, meniscal tear, preoperative KT-1000 side-to-side difference, and remnant preservation were included as independent variables in the multiple linear regression analysis. After the multiple linear regression analysis, only preservation of the remnant was significantly associated with postoperative KT-1000 side-to-side difference ($p = 0.020$, Table 5).

Discussion

In comparing the three groups in this study, the group that underwent new remnant-preserving anatomical double-bundle ACL reconstruction[16] showed no significant differences in clinical scores compared to the resected remnant group and the absent group. However, the preserved group had significantly better anterior stability than both the resected and absent groups. Moreover, multiple linear regression analysis showed that the remnant preservation significantly affected postoperative KT-1000 side-to-side difference, even when corrected for age, meniscal tear, and preoperative KT-1000 side-to-side difference. There were no differences between groups in terms of postoperative complications, including re-rupture and cyclops syndrome. From these results described above, we believe that the technique using the remnant for structural augmentation in this study is very safe and improves postoperative stability.

Remnant-preserving ACL reconstruction is one approach for achieving good anterior stability in ACL reconstruction, which is expected to promote graft remodelling by passing the graft into the remnant in conventional remnant-preserving methods that have been previously reported.[9,10] In several animal studies, it has been reported that good maturation can be obtained by cell recruitment from grafted tendons and the associated revascularization from the severed original ACL tissue.[24–26] However, in humans, some reports suggest that remnant preservation does not actually improve stability.[11–13] Another study reported that there was no difference in the anterior stability and synovial coverage at second-look arthroscopy when there was little graft coverage with the remnant.[11] Because the volume and quality of remnants in humans vary greatly from case to case, we speculate that the results of conventional remnant-preserving methods are inconsistent, as they are greatly influenced by the condition of the remnant and surgical technique. In the present study, which was performed using a new surgical technique that does not pass the graft through the remnant, the remnant preservation improved the postoperative stability.

In the new remnant preserving method of this study, the tibial bone tunnels are created inside the normal attachment. The AM bundle then passes in front of the remnant, and the PL bundle passes behind the remnant, thereby sandwiching the remnant between them (Fig. 3). Several studies have reported that remnants contribute to either the anteroposterior or rotational performance of the knee joint to some extent, depending on the time from injury and the position of attachment site.[15,27–29] The reason for the

Table 1
Demographic and clinical factors of patients in three groups.

Variable	Preserved group (n = 34)	Resected group (n = 26)	Absent Group (n = 45)	P Value			
				All	Preserved vs Resected	Preserved vs Absent	Resected vs Absent
Age, y, mean ± SD (range)	27.9 ± 11.4 (14–55)	27.0 ± 11.9 (14–49)	21.7 ± 8.8 (14–50)	0.022*	>0.99	0.033*	0.13
Gender, male/female, n	18/16	9/17	18/27	0.33	0.59	0.80	>0.99
Height, cm, mean ± SD (range)	164 ± 8 (148–178)	165 ± 9 (151–184)	164 ± 8 (149–188)	0.90	>0.99	>0.99	>0.99
BMI, kg/m^2, mean ± SD (range)	23.4 ± 4.9 (17.1–46.3)	23.8 ± 4.0 (17.5–34.9)	21.8 ± 2.9 (17.6–32.2)	0.073	>0.99	0.22	0.13
Injury to operation interval, mo, median (range)	4 (1–72)	4 (1–72)	3 (1–300)	0.35	>0.99	0.67	0.69
Preoperative Lysholm knee score, mean ± SD (range)	81.8 ± 10.4 (51–100)	78.1 ± 12.6 (51–100)	77.4 ± 13.5 (20–95)	0.27	0.76	0.35	>0.99
Preoperative Tegner activity scale, mean ± SD (range)	5.9 ± 1.1 (4–9)	5.6 ± 1.4 (3–7)	6.0 ± 1.4 (3–8)	0.42	>0.99	>0.99	0.58
Preoperative KT-1000 side-to-side difference, mm, mean ± SD (range)	5.5 ± 2.7 (2.0–12.5)	6.1 ± 2.9 (3.0–15.0)	7.0 ± 2.5 (3.0–12.0)	0.077	>0.99	0.075	0.66
Remnant, Crain type I/II/III/IV, n	2/28/4/0	8/13/5/0	0/0/0/45	<0.001*	0.052	<0.001*	<0.001*
Meniscal tear, n (%)	19 (56)	17 (65)	36 (80)	0.068	>0.99	0.082	0.77
Meniscal repair, n (%)	17 (50)	12 (46)	25 (56)	0.73	>0.99	>0.99	>0.99
Partial meniscectomy, n (%)	2 (6.0)	4 (15)	8 (18)	0.33	>0.99	0.52	>0.99
Cross-sectional area of anteromedial bundle, mm^2, mean ± SD (range)	21.6 ± 3.3 (16.5–29.5)	20.9 ± 5.0 (11.9–35.7)	23.0 ± 4.7 (15.0–38.5)	0.14	>0.99	0.53	0.18
Cross-sectional area of posterolateral bundle, mm^2, mean ± SD (range)	17.9 ± 4.3 (7.7–26.7)	16.5 ± 4.9 (8.3–24.0)	18.9 ± 4.2 (9.2–28.5)	0.10	0.71	0.98	0.098

Data described as mean ± standard deviation (range) or median (range), the number and percentage of cases in each group. *P-value < 0.05. SD, standard deviation. BMI, Body mass index. AM, anteromedial. PL, posterolateral.

Table 2
Tibial and femoral tunnel position in three groups.

Tunnel Position	Preserved group (n = 34)	Resected group (n = 26)	Absent Group (n = 45)	P Value
Femur				
AM-Depth, %, mean ± SD (range)	21.8 ± 4.3 (12.5–30.3)	22.3 ± 4.7 (12.1–35.2)	22.2 ± 5.1 (13.0–34.6)	0.89
AM-Height, %, mean ± SD (range)	26.4 ± 9.4 (9.2–45.5)	25.5 ± 10.9 (9.9–51.2)	24.1 ± 8.5 (10.2–41.0)	0.64
PL-Depth, %, mean ± SD (range)	33.6 ± 5.9 (20.6–44.3)	33.9 ± 7.8 (18.7–54.3)	33.7 ± 6.3 (18.9–48.2)	0.99
PL-Height, %, mean ± SD (range)	56.9 ± 8.8 (41.5–80.1)	53.5 ± 8.7 (40.0–70.1)	55.1 ± 9.0 (36.0–70.5)	0.23
Tibia				
AM-ML, %, mean ± SD (range)	45.8 ± 2.5 (40.8–50.5)	45.5 ± 3.1 (37.0–54.1)	45.3 ± 2.3 (41.1–49.7)	0.73
AM-AP, %, mean ± SD (range)	31.2 ± 5.2 (17.2–42.6)	30.2 ± 4.9 (17.9–47.8)	31.6 ± 3.9 (25.7–40.1)	0.41
PL-ML, %, mean ± SD (range)	47.5 ± 2.6 (42.2–52.3)	46.5 ± 3.0 (38.3–55.1)	46.2 ± 2.5 (40.9–51.0)	0.16
PL-AP, %, mean ± SD (range)	46.7 ± 5.7 (29.7–56.9)	46.7 ± 4.7 (36.2–54.9)>	46.5 ± 6.3 (32.9–60.0)	0.97

Data are shown as mean ± standard deviation (range). AM, anteromedial; PL, posterolateral; ML, mediolateral; AP, anteroposterior. SD, standard deviation.

Table 3
Clinical results in three groups.

Outcome Measure	Preserved group (n = 34)	Resected group (n = 26)	Absent Group (n = 45)	P Value			
				All	Preserved vs Resected	Preserved vs Absent	Resected vs Absent
Postoperative Lysholm knee score, mean ± SD (range)	94.9 ± 6.7 (77–100)	96.7 ± 3.5 (90–100)	96.3 ± 5.8 (72–100)	0.41	0.66	0.86	>0.99
Postoperative Tegner activity scale, mean ± SD (range)	5.2 ± 1.2 (3–7)	4.9 ± 1.3 (3–7)	4.9 ± 1.6 (2–8)	0.58	>0.99	>0.99	>0.99
Postoperative IKDC subjective score, mean ± SD (range)	89.8 ± 9.7 (67.8–100)	93.4 ± 5.5 (78.2–100)	91.0 ± 10.9 (51.7–100)	0.34	0.44	>0.99	0.95
Postoperative KT-1000 side-to-side difference, mm, mean ± SD (range)	0.3 ± 1.6 (-5 to 3.5)	1.6 ± 2.3 (-2.5 to 7.0)	1.6 ± 1.7 (-2 to 6)	0.0054*	0.0029*	0.0085*	>0.99
Re-rupture, n (%)	0 (0)	2 (7.7)	0 (0)	0.060	>0.99	>0.99	0.39
Cyclops, n (%)	0 (0)	0 (0)	2 (4.4)	0.51	>0.99	>0.99	>0.99
Infection, n (%)	0 (0)	0 (0)	1 (2.2)	>0.99	>0.99	>0.99	>0.99

Data described as the mean ± standard deviation (range) or the number and percentage of each group. *P-value < 0.05. IKDC, International Knee Documentation Committee; SD, standard deviation.

Table 4
Univariate linear regression analysis of individual patient variables for postoperative side-to-side anterior laxity.

Variable	Effect (95% CI) (mm)	P Value
Age, y	−0.03 (−0.06, 0.003)	0.072
Gender, % Female	−0.32 (−1.08, 0.44)	0.40
Height, cm	1.67 (−2.88, 6.21)	0.47
BMI, kg/m^2	−0.01 (−0.11, 0.08)	0.81
Injury to operation interval, mo	0.004 (−0.006, 0.013)	0.45
Preoperative Tegner activity scale, level	0.12 (−0.17, 0.40)	0.43
Meniscal tear	0.64 (−0.17, 1.44)	0.12
Meniscal repair	0.41 (−0.33, 1.16)	0.27
Partial meniscectomy	0.55 (−0.55, 1.65)	0.33
Preoperative KT-1000 side-to-side difference, mm	0.12 (−0.03, 0.28)	0.12
Remnant Preservation	−1.28 (−2.05, −0.52)	0.001*

Data are shown as regression coefficients (95% confidence intervals). *P-value < 0.05.
CI, confidence intervals; BMI, body mass index.

Table 5
Multiple linear regression analysis of individual patient variables for postoperative side-to-side anterior laxity.

Variable	Effect (95% CI) (mm)	P Value
Age, y	−0.03 (−0.07, 0.01)	0.17
Meniscal tear	0.72 (−0.13, 1.57)	0.097
Preoperative KT-1000 side-to-side difference, mm	0.09 (−0.06, 0.24)	0.25
Remnant Preservation	−1.05 (−1.93, −0.17)	0.020*

Data are shown as regression coefficients (95% confidence intervals). *P-value < 0.05.
CI, confidence intervals.

improved postoperative stability with the new remnant preservation method may be attributed to reduced initial stress on the grafted tendon by the biomechanical function of the preserved remnant. In ACL reconstruction, it has been reported that graft loosening and an accompanying increase in anterior movement may occur during the initial stage.[30] In a rat ACL reconstruction model, it was reported that a group with a reduced initial axial loading significantly increased the tensile strength and bone-tendon healing compared to a group with immediate loading or immobilization.[31] Since the new method used in this study preserves the remnant without damaging it, the preserved biomechanical stability may reduce the initial postoperative stress on the grafted tendon, which could lead to better bone-tendon healing, tendon maturation, and improved anterior stability. Moreover, remnant preservation of this procedure may have increased the overall cross-sectional area, including the grafted tendon and remnant, which may have affected the improvement in anterior stability. There have been several biomechanical studies that have demonstrated that the cross-sectional area of the grafted tendon affects the rupture strength[32] and postoperative looseness[33] of the grafted tendon, which may be another reason for the good stability.

There were slightly fewer re-ruptures and cyclops debridement in this study compared to previous relevant studies.[12,34] With regard to re-ruptures, the age of the patients in this study was slightly older than in previous relevant studies, which may have affected the results.[34] In terms of cyclops lesions, Nakayama et al.[12] suggested that in conventional remnant-preserving ACL reconstruction, the remnant anterior to the tendon graft impinges on the femoral intercondylar notch, resulting in cyclops lesions. In the present study, the new remnant-preserving method may have resulted in fewer cyclops lesions because the remnant was positioned behind or lateral to the AM bundle tendon graft.

Limitation

There are several limitations to this study. First, the most noteworthy limitation of this study is its retrospective non-randomized design with different age distributions among the groups. The preserved group had a slightly better preoperative KT-1000 side-to-side difference and a slightly higher rate of meniscus injury than the absent group, although the difference was not significant. Moreover, the resected group that required remnant resection for bone tunnel creation may have included many cases with remnant volume that was large and difficult to preserve. These differences in secondary constraining structures such as ligaments, joint capsule tissue, and meniscus may have affected the differences in postoperative stability.[35–37] However, the study design is unlikely to have affected the outcome, since the surgical techniques among the groups were almost identical. In multiple linear regression analysis, remnant preservation was significantly correlated with postoperative anterior stability even after adjusting for age, meniscal tears, and preoperative anterior stability. Secondly, the remnant type, quality, and whether or not the remnant was preserved are all subjective assessments based on arthroscopic findings. However, a system for objective and quantitative evaluation has not been developed and should be an area for future study. Thirdly, this study did not evaluate the condition of the reconstructed ligament after surgery by second-look arthroscopy or MRI, but only speculated on the mechanism that may have affected the improvement of anterior stability. In the remnant preservation method used in this study, ACL reconstruction was performed by focusing on the biomechanical function of the remnant; however, in reality, the remnant may have loosened and lost its biomechanical function after tendon graft fixation, and the stability may have improved due to an unrelated cause. Fourth, this study did not show a significant difference in clinical scores from patients, and a statistically significant improvement in the postoperative anterior stability of 1.3 mm may not be considered clinically meaningful. However, few comparative studies on ACL reconstruction, including those on remnant preservation, have found significant differences in clinical scores.[38–40]

Conclusions

Although there were no differences in clinical scores, the ACL reconstruction with the new preservation technique showed good anterior stability and no difference in the frequency of complications.

Ethical approval

This study was approved by the ethics committee of Shinshu University School of Medicine.

Informed consent

Informed consent was obtained in the form of opt-out on our hospital web-site.

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Declaration of competing interest

The authors have no conflict of interests to declare.

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