An Arthroscopic Second-Look Study on the Effect of Remnant Preservation on Synovialization of Bone–Patellar Tendon–Bone Allograft in Anterior Cruciate Ligament Reconstruction

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**Purpose:** To assess the effects of preserved more anterior cruciate ligament (ACL) remnant on synovial coverage, knee stability, and function after bone patellar–tendon–bone (BPTB) allograft reconstruction through second-look arthroscopy and follow-up study. **Methods:** From June 2007 to February 2009, 51 patients received single bundle BPTB allograft ACL reconstruction and second arthroscopic examination. The patients were divided into 4 types according to the types of ACL remnant: type 1, 18 had bridging between the posterior cruciate ligament and the tibia; type 2, 21 had bridging between the intercondylar notch roof and the tibia; type 3, 4 had bridging between the lateral condyle and the tibia; and type 4, 8 subjects had no ACL remnants. Clinical results were evaluated with the KT-1000 maximum displacement test and Lysholm scale at mean 12.3- and 53.5-month follow-up. Second-look synovium coverage was recorded as follows: covering 25% or less, 25% to 50%, 50% to 75%, and more than 75%. **Results:** Mean percentage of synovium coverage, Lysholm scale, and KT-1000 side-to-side difference were poorer in types 3 and 4 than the other 2 types at mean 12.3-month follow-up without statistical differences. The result of the final follow-up was comparable with the first one. Four patients had ruptured grafts and accepted revision surgery. Three of them belonged to types 3 and 4, and 1 patient with sport trauma belonged to type 2. There were other 11 patients with different types of impingement and partial absorption of grafts. **Conclusions:** Although lack of statistical power, follow-up study and second-look arthroscopy showed that preserved type 3 and 4 ACL remnant caused poorer synovium coverage and might lead to earlier failure when using BPTB allograft. Early minor laxity at 12.3-month follow-up seemed to be not progressive at the final follow-up. **Level of Evidence:** Level III, case-control study.

Anterior cruciate ligament (ACL) reconstruction surgery is a common procedure nowadays. A successful outcome depends on multiple factors including anatomic graft placement with secure fixation, graft incorporation, graft revascularization, and ligamentization. ACL remnant was reported to play an important role in anterior knee constraint, proprioception, biomechanical function, and graft protection. To preserve as much ACL remnant tissue as possible during reconstruction surgery might save its residual function and improve performance of new graft. So ACL reconstruction using the remnant preservation or augmentation technique has attracted much attention in recent years.

Remnant tissue could accelerate graft revascularization, promote ligamentization and graft incorporation, and thus lead to a better stable recovery. The extent of synovialization is reported to be positively correlated with clinical outcomes. According to its injury pattern and history, ACL remnant had different appearances and could be classified into 4 types according to Crain description: type 1, bridging between the posterior cruciate ligament (PCL) and the tibia (Fig 1); type 2, bridging between the roof of the intercondylar notch and the tibia (Fig 2); type 3, bridging between the lateral wall of the intercondylar notch and the tibia (Fig 3); and type 4, remnant preservation.
no substantial ACL remnants (Fig 4). Maeda et al.\(^2\) reported that preserved type 3 remnant could increase anterior knee stability. But the relationship between types of preserved ACL remnant and extent of post-operative graft synovialization and knee function has not been well documented. Whether all types of ACL remnant could be related to a positive result is still unclear.

Several investigators have developed ACL reconstruction techniques with preservation of the ACL remnant tissue\(^1\)\(^3\)-\(^1\)\(^9\) and reported early better stability and knee function. But up to now there was no report about the influence of remnant preservation on knee stability and function after allograft ACL reconstruction. The purpose of this study was to assess whether different types of preserved ACL remnant would affect synovial coverage, knee stability, and function after bone–patellar tendon–bone (BPTB) allograft reconstruction. We hypothesized that all preserved ACL remnants would improve graft synovialization, knee stability, and function.

**Methods**

**Patient Selection**

From June 2007 to February 2009, 109 patients had received ACL reconstruction in our hospital. A total of 51 patients (39 male and 12 female) were included in this study. All surgical options were explained to the patients including BPTB autograft, artificial ligament, and BPTB allograft. The patients were told that other graft choices such as hamstring tendon were not included because special surgical instruments were not available in our center at that time. Inclusion criteria included the following: patients were older than 18 and younger than 40 years; patients chose allograft BTB and agreed to be included in this study; the tibial bone block inside the tunnel was shorter than 15 mm; and an extra transverse Kirschner wire was used to fix the tibial bone block. The fixation standard on the tibial side was set to be at least over 15 mm inside the tibial tunnel. If allografts were too long and the tibial bone block outside the tunnel had to been cut that made the block inside the tunnel shorter than 15 mm, a transverse Kirschner wire was used. Exclusion criteria included post-traumatic arthritis, associate ligament injury, repaired meniscus (which may cause unexpected arthroscopy for suture or healing failure and influence the result of this study), and cartilage lesion of Outerbridge grade III or IV larger than 1.0 cm in diameter.

Because a 55° tibial tunnel was routinely used in all surgeries and the length of the femoral tunnel was made equal to the femoral bone block, there was a possibility of longer graft for some patients. In all the 51 patients, the tendon part of the allografts was found to be relatively too long and a less than 15-mm tibial bone block was left inside the tunnel. So except for a bio-absorbable interface screw, 1 extra Kirschner wire was used to fix the tibial bone block. All patients agreed to accept second-look arthroscopy when they underwent Kirschner wire removal surgery. This procedure should be carried out at least 6 months after the reconstruction surgery.

**Graft Preparation**

Allografts from the allograft bank in our hospital were harvested sterilely from young donors (<35 years) who died from traffic accidents. The mean age was 29.6 ± 4.5 years. Grafts were packed after dehydration and deproteinization. Cobalt-60 irradiation (1.5 Mrad) for
20 hours was selected for sterilization. All allografts were preserved in the freezer at \(-35^\circ\text{C}\) to \(-30^\circ\text{C}\) for at least 3 months before use.\textsuperscript{20} At the beginning of surgery, the graft was defrosted and made into the same size. The diameter of the femoral bone block was 9 mm and that of the tibial bone block 10 mm. The width of the tendon was 9 to 10 mm.

**Surgical Technique**

Surgeries were finished under arthroscopy by an experienced sport surgeon (H.C.) with the same technique. We used an air tourniquet in all cases. Arthroscopy was performed with an anterolateral and anteromedial approach. Combined injuries such as meniscus tear, cartilage lesion (<1 cm in diameter), and synovial plica were treated before ACL reconstruction.

After appearances of remnant were evaluated, a point-to-arm aimer was used to preserve remnant when preparing a tibial tunnel. The middle point between the posterior horn of the lateral meniscus and the anterior horn of the medial meniscus was used as the reference point. After a guidewire was drilled into the tibia through the remnant sleeve, the guidewire position was confirmed with a C-arm fluoroscope. A 55° tibial tunnel of 10-mm diameter was routinely made.

The operator made the femoral tunnel through the anteromedial portal. A 7-mm posterior offset aimer was used. The reference of the tunnel position was set at 10 o’clock for the right knee (2 o’clock for the left knee) position when the knee was flexed at 120°. When operating on patients with type 3 remnant who had bridging between the lateral wall of the intercondylar notch and tibia, the operator tried to preserve the remnant by lifting the adherence of the tendon on the lateral wall to make room for the femoral tunnel (Fig 3). Preparation of the femoral tunnel would not influence intact of ACL remnant for type 1 (Fig 1) and 2 (Fig 2) remnant because bridging of remnant is on the intercondylar notch and PCL. The length of the femoral tunnel was made equal to the length of the femoral bone block of the allograft. This left the tendon-bone junction site of the graft at exactly the entrance of the femoral tunnel after the graft was introduced. The operator tried to avoid the “windshield” effect in this way because the bone block healed better in the tunnel and there were less tendon-bone healing problems by using this technique.

Grafts were tensioned at 45° and fixed with bioabsorbable interface screws on both sides. In this type of patients, the bone block inside the tibial tunnel was shorter than 15 mm. Because the operator drilled the femoral tunnel just the length of the femoral bone block to leave the tendon-bone junction site exactly at the entrance of the femoral tunnel, the graft seemed to be longer than expected when a relatively long allograft was used. The tibial bone block outside the tibial tunnel was cut and a less than 15-mm bone block was left inside. Because the standard of tibial fixation with only an interface screw was set to be at least 15 mm inside the tunnel, one 2.0-mm Kirschner wire was used to transversely fix the tibial bone block to make a safe fixation (Fig 5).

The rehabilitation protocol was the same for all patients. Range-of-motion training and isometric quadriceps training were applied immediately after operation. Isotonic quadriceps training started 2 weeks after surgery. Patients were allowed to walk with toe-touch...
weight bearing under protection of long leg splint within 6 weeks postoperatively. Full weight bearing was allowed 6 weeks after surgery with short brace protection until 4 months postoperatively.

The configuration of the ACL remnants and their attachments to the femur and tibia were characterized according to arthroscopy video by the third author who did not participate in the whole process of treatment of the patients. The ACL remnants were classified into 4 morphologic patterns as Crain described: type 1, bridging between the PCL and the tibia; type 2, bridging between the roof of the intercondylar notch and the tibia; type 3, bridging between the lateral wall of the intercondylar notch and the tibia; and type 4, no substantial ACL remnants.

Follow-up Study
All patients were followed up and evaluated twice in the outpatient department by the third author independently. The first follow-up was before the second-look arthroscopy surgery and the second follow-up was at the end of this study. The final follow-up result for patients who received revision surgery was recorded before revision. Lachman and pivot-shift tests were performed. Lateral- and anteroposterior-view (Figs 5 and 6) roentgenograms were taken at the time of follow-ups. Enlargement of bone tunnels should be recorded. Rupture of ACL was defined as sudden loss of anterior stability with injury history. Attenuation of ACL was defined as failure of ACL without clear injury history and diagnosed by second-look arthroscopy. Clinical data included assessment of the side-to-side difference by use of a KT-1000 arthrometer and Lysholm scale.

Arthroscopic Second-Look Study
All patients who underwent second-look arthroscopy were examined by the first author after the Kirschner wire was removed. The third author examined videos of second-look arthroscopy surgery independently and recorded the extent of synovialization of graft by the method described by Noh et al. Formation of a synovial membrane around the graft was recorded with percentage measurement under second-look arthroscopy. Synovium coverage was recorded as follows: covering 25% or less (Fig 7), 25% to 50% (Fig 8), 50% to 75% (Fig 9), and more than 75% (Fig 10).

Statistical Analysis
We used the analysis of variance model and the Student-Newman-Keuls (SNK) method for statistical analysis. $P < .05$ was regarded as significantly different in statistics. A power study was used to evaluate the statistical power of this study ($\alpha = 0.05$, $1-\beta = 0.90$).
Results

All patients were successfully followed up. There were 28 left knees and 23 right knees. The mean age was 26.7 ± 4.9 years. The mean time between injury and ACL reconstruction was 2.8 months. The mean hospital stay for ACL reconstruction surgery was 6.7 days. The mean duration from ACL reconstruction to second arthroscopy was 12.3 months (ranging from 10 months to 19 months) and follow-up time was 53.5 months (ranging from 44 to 64 months).

According to the types of remnant, there were 8 patients as type 1, 21 patients as type 2, 4 patients as type 3, and 8 patients as type 4. The mean synovial coverage extent of a certain type was also calculated as less than a mean percentage value. Type 1 (≤76.4%) and type 2 (78.6%) had better synovium coverage than type 3 and type 4 (Table 1).

Lachman and pivot-shift tests were positive in 6 cases (11.8%). All patients were recovered to a normal level of activities of daily living. Thirty-five patients (68.6%) had recovered to the preinjury sports level. The KT-1000 side-to-side difference (mean, 3.4 ± 0.67 mm) was less than 3 mm in 29 patients (56.9%), 3 to 5 mm in 18 patients (35.3%), and more than 5 mm in 4 patients (7.8%). The Lysholm scale and the KT-1000 side-to-side difference were poorer in types 3 and 4 than the other 2 types at mean 12.3-month follow-up. With regard to the power analysis result, when power (1−β) was set as 0.90 and the significance level of testing as .05, we calculated a sample size that was greater than 120. The final sample size that met the final selection criteria was less than 120. So the hypothesis testing was underpowered to find out the difference between different types. We use the analysis of variance model to compare the 4 types, and get the result (Lysholm): F = 7.22, P = .0005; differences are statistically significant among the 4 types of patients. The SNK method found that Lysholm differences are statistically significant between type 1 and type 2, type 1 and type 3, type 2 and type 3, and type 3 and type 4, whereas the rest of comparisons showed no statistical significance. We then use the analysis of variance model again to compare the 4 types, and get the result (KT-1000): F = 4.21, P = .0103. Differences are statistically significant among the 4 types of patients. The SNK method found that KT-1000 differences are statistically significant between type 1 and type 3, type 1 and type 4, type 2 and type 3, and type 2 and type 4, whereas the rest of comparisons showed no statistical significance (Table 2).

Four patients had failed ACL grafts on the first follow-up before the second arthroscopy at mean 6.7 months. There were 2 patients as type 4, 1 as type 3, and 1 as type 2. The previous 3 patients could not recall any history of injury to the operated knee. According to the second-look arthroscopy, they were diagnosed as attenuated (Fig 11) ACL for there was no tensioned fiber left and most allografts were absorbed (Fig 6). These 3 patients were revised with autograft BTB. The fourth patient belonged to type 2. He had a history of acute knee injury 9 months after reconstruction surgery when he was playing basketball (Fig 12). Full synovium coverage was found on the surface of the allograft during reconstruction surgery (Fig 10). The patient was revised with autograft BTB. At the time of the final follow-up, these 4 patients were satisfied with their revision surgery.

Fig 7. Synovium coverage covering 25% or less.

Fig 8. Synovium coverage covering 25%-50%.
In other 11 patients, we found partial tear of grafts caused by impingement on the intercondylar notch or the lateral condyle. There were 3 anterior impingements on the intercondylar notch, 7 lateral impingements on the femoral condyle, and 1 combined impingement of both (Table 1). There was no synovium coverage (Fig 7) at all impingement sites and graft fibers were partially ruptured or absorbed. Grafts of the other 36 patients were intact and well covered with synovium (Fig 9). All bone grafts were stable and fused in tunnel according to roentgenograms at the time of follow-up. No infection, enlargement of tunnel, fibrosis, and deep vein thrombosis were found at the time of follow-up.

Discussion

This study was designed to evaluate the contribution of preserved remnant on graft synovialization, knee stability, and function. To testify the maximal capacity of remnant on the influence of synovialization, only patients who chose BPTB allografts were included in this study. That allograft had poorer character for revascularization and preserved remnant could be the primary reason for formation of synovium and surface blood supply. Although allograft is one of the optional choices for ACL reconstruction, the process of synovium formation and revascularization over allograft could be slow or even unsuccessful. Previous studies also indicated that allograft BPTB may cause late formation of surface synovium compared with autograft, whereas preserved remnant may improve it. So this study was designed to find out whether synovium formation over allograft may mainly depend on preserved remnant, and whether different kinds of remnants have a nonequal effect on the acceleration of resynovialization. These disadvantages of allografts were used to testify the maximal capacity of ACL remnant in effect of synovium formation. If all types of remnants could improve synovium formation of allograft, improvement on revascularization for other kinds of grafts could be expected.

According to the statistical analysis of this study, patients with no remnant (type 4) or lower position remnant (type 3) tend to lead to the formation of poorer synovium coverage, poorer Lysholm score, and KT-1000 result. Some unexpected early failure cases were also found in types 3 and 4. This suggests that potential pitfalls of poorer remnant preservation and synovium recovering may cause early failure in patients who used allografts. Noh et al. also reported that the extent of synovialization is positively correlated with clinical outcome. Although without powerful statistical significance, lack or loss of remnant may lead to poor synovial formation and possible early failure according to our study. A comparison of mean 12.3-month and 53.5-month follow-up results showed that a statistical difference between different types suggested that the early laxity caused by impingement was not progressive according to follow-up.

Preserved ACL remnant had been reported to accelerate revascularization and promote graft incorporation. However, the advantages of remnant preservation are not easy to show by clinical scores or physical examinations. The extent of synovialization could not be recognized by clinical evaluation either. Second-look arthroscopy had been used to verify the
extent of synovialization and synovium blood supply over grafts. In this study, the extent of synovialization with relationship to different types of remnant preservation was also evaluated by second-look arthroscopy. Evaluation of mean percentage of synovium coverage was used to describe the extent of synovialization. In this type of patients, remnant bridging from the roof of the intercondylar notch and PCL tends to lead to better synovium coverage. The authors assumed that preservation of blood supply could be one of the most important reasons. Several studies had indicated that preservation of ACL remnant may enhance revascularization and cellular proliferation of the graft after ACL reconstruction, because the ACL remnant tissue has good subsynovial and intrafascicular vascularity. Main blood supply to ACL is the ligament branch of the middle genicular artery that comes from the upper third of ACL posteriorly. ACL remnants with good blood supply and abundant fibrous leftover survived from low-energy injury tend to form bridging from the femur. The blood supply in remnant survived from the injury and reconstruction surgery tends to ease the process of incorporation. Short of ACL remnant blood supply caused either by injury itself or clearance during operation could lead to absorption of remnant, failure of adherence, or delayed formation of synovium. For patients with type 4 ACL remnants, no remnant was found during the first reconstruction surgery and poor blood supply may be responsible for poor resynovialization.7

Type 3 ACL remnant also had good adherence and blood supply. But in this study, preservation of synovium was difficult during reconstruction surgery and resynovialization of graft was rarely found. Because it is close to ACL femoral footprint, it could be easily damaged during femoral tunnel preparation. It was reported that resection of the ACL scar resulted in a measurable increase in passive anterior laxity in a subset of ACL deficient knees.1 Type 1 and 2 remnants were far

Table 1. Number of Synovial Coverage Types in Reconstruction Surgery; Number of Ruptured Grafts and Impingement Type of Graft in Different Types of Patients During Second Look Arthroscopy

<table>
<thead>
<tr>
<th>Remnant Types</th>
<th>Synovial Coverage1</th>
<th>Ruptured Grafts</th>
<th>Impingement Type1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;25%</td>
<td>25%-50%</td>
<td>50%-75%</td>
</tr>
<tr>
<td>1 (n = 18)</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>2 (n = 21)</td>
<td>1</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>3 (n = 4)</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4 (n = 8)</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>8</td>
<td>13</td>
</tr>
</tbody>
</table>

1ACL remnant could be classified into 4 types: type 1, bridging between the posterior cruciate ligament and the tibia; type 2, bridging between the roof of the intercondylar notch and the tibia; type 3, bridging between the lateral wall of the intercondylar notch and the tibia; and type 4, no substantial ACL remnants.

1Formation of a synovial membrane around the graft was recorded as follows: covering 25% or less of the surface of the graft; 25%-50%; 50%-75%; and more than 75%. The percentage value was evaluated by the third author based on surgical video.

1Impingement of grafts could be classified into 3 types: impingement on intercondylar notch, lateral condyle, or combination of both.

Table 2. Follow-up Result Before Second Arthroscopy and at the Time of Final Follow-up for Patients With Different Types of Remnants (x ± SD)

<table>
<thead>
<tr>
<th>Patient Groups</th>
<th>Follow-up</th>
<th>Lysholm</th>
<th>KT, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>x SD</td>
<td>95% CI</td>
</tr>
<tr>
<td>1 (n = 8)</td>
<td>Before second arthroscopy</td>
<td>79.6</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>Final1</td>
<td>82.4</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>2.8</td>
<td>2.4</td>
</tr>
<tr>
<td>2 (n = 4)</td>
<td>Before second arthroscopy</td>
<td>82.3</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>80.6</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>−1.7</td>
<td>1.9</td>
</tr>
<tr>
<td>3 (n = 21)</td>
<td>Before second arthroscopy</td>
<td>91.2</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>91.3</td>
<td>9.7</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>0.1</td>
<td>1.4</td>
</tr>
<tr>
<td>4 (n = 17)</td>
<td>Before second arthroscopy</td>
<td>89.8</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>90.7</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>0.9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

CI, confidence interval; KT, KT-1000 maximum displacement test; SD, standard deviation.

1Before second arthroscopy follow-up: The follow-up done before second-look arthroscopy when the patient came to receive internal fixation removal surgery.

1Final follow-up: the last follow-up before this study was ended. For patients who received revision surgery, the final follow-up result was before revision surgery.
more anterior to anatomic ACL femoral footprint and did not affect positioning of the femoral tunnels. So soft tissue sleeve and blood supply from up third behind could be easily preserved. Our result is supported by the study of Nakase et al.,20 which suggested that type 2 remnant should be preserved as much as possible when ACL reconstruction surgery is performed.

There were 3 early failure cases in patients with poorer synovium coverage because of spontaneous rupture. The reason for rupture of uncovered graft is unknown. These 3 patients (5.9%) in types 3 and 4 could not recall any history of injury. Impingement of graft had been aroused as one of the possible reasons of early failure in this study. In the other 11 patients, the authors found damage of superficial graft fiber and failure of synovial formation at the site of impingement. Exposure of damaged allograft fibers to joint fluid circumstance could easily lead to absorption of graft. In these cases, the damage caused by impingement of graft was a slow process and could not be recognized by the patient. The authors assumed that mistakes of tunnel mal-positioning could be early exposed when no synovium recover and incorporation happen. Mal-positioning and the absence of ACL remnant protection could easily cause early failure and laxity especially when using allografts. Patients with partial tear were distributed in type 1 and 2 remnant. One of the important reasons was that these 2 types of patients had occupied over three-fourths of the whole patient population. Also the authors believed that impingement actually caused damage to graft in types 3 and 4.

But when there was no successful synovium coverage formation, fiber tear caused by impingement could eventually lead to absorption of graft, whereas for allografts well covered by synovium, minor partial tear of graft caused by impingement seemed to be not progressive at the final follow-up. Considering some cases of early failure and partial tear, the follow-up result of this study seemed to be inferior to those reported in previous studies. We believed that the reason is γ-irradiation processing especially when it was over 2.0 Mrad of Co-60 irradiation. In our previous study, we found that dehydration, deproteinization, and irradiation could be the reasons why the clinical result of processed allograft seemed to be inferior to those of fresh-frozen allograft and autograft.19

Limitations

The multiple limitations of this study included that there were no autograft BTB cases included for comparison with allograft. Only patients who chose allografts were included in this study and selection of grafts were not randomized. The limitation that only those patients who needed to have the K-wire were included was because of lack of consistency to the second-look arthroscopy and the authors hoped to increase second-look arthroscopy rate. Although the authors suggested the patients to receive second surgery at 1-year follow-up, most patients chose second surgery based on their

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**Fig 11.** Second-look arthroscopy picture of a tenuated anterior cruciate ligament (ACL) graft caused by impingement. The uncovered fiber was ruptured and absorbed.

**Fig 12.** A 27-year-old male patient who had a history of acute injury when he was playing basketball. Second look at allogorous BPTB graft 9 months after ACL reconstruction. The surface of the tendon was well covered by vascularized synovium. The graft was ruptured on the femoral side. (ACL, anterior cruciate ligament; BPTB, bone patellar—tendon—bone.)
own decision. Although we got 100% follow-up, we do regard that as one of the hard parts during this follow-up study. But most of the patients received the second surgery at around 12 months. At the time of the study, patients needed to be admitted to be fully covered by medical insurance. And because rehab centers were very few, patients needed to learn how to do early rehab under the supervision of surgeons. So patients included in this study needed to be hospitalized for approximately 7 days. The result of allograft reconstruction was relatively inferior to those reported before and may in influence the efficacy of the study. We regarded the reason of the inferior result to be \( \gamma \)-irradiation processing and we have also reported this before. Also, the number of patients included in this study was not enough to get a powerful statistically confirmative conclusion according to our power study. Further research and longer follow-up studies were needed to evaluate the value of preserving ACL remnants.

**Conclusions**

In conclusion, remnant adhered to the intercondylar notch roof and PCL will be easier to be preserved and improve graft synovialization than that of ACL remnant deficit or remnant adherence to the femoral condyle. Although the power of our hypothesis testing was not enough according to our power study, the analysis of variance model and the SNK method found that there are differences. Statistical analysis suggested that patients with ACL remnant bridging from the PCL and the roof of the intercondylar notch had better Lysholm score and KT-1000 result than patients with ACL remnant bridging from the lateral condyle or no remnant left. Second-look arthroscopy showed better synovium coverage in the previous 2 types. Impingement of grafts and failure of synovium coverage could be the main reasons for a worse clinical follow-up result and early failure especially when using BPTB allograft. But early laxity at 12.3-month follow-up caused by impingement seemed to be not progressive during a farther long-term follow-up study.

**References**


