Tunnel Volume Enlargement After Posterior Cruciate Ligament Reconstruction: Comparison of Achilles Allograft With Mixed Autograft/Allograft—A Prospective Computed Tomography Study

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Purpose: The purpose of this study was to evaluate and compare femoral and tibial tunnel volume enlargement (TVE) after arthroscopic posterior cruciate ligament (PCL) reconstruction by remnant bundle preservation using Achilles allograft or mixed graft. Methods: Seventy-eight patients undergoing primary arthroscopic single-bundle PCL reconstruction were initially included. Fifty-six of these patients underwent follow-up for a minimum of 1 year postoperatively and were divided into 2 groups: group A received Achilles allograft (n = 27), and group B received mixed graft (n = 29). The clinical evaluation included the International Knee Documentation Committee rating, Lysholm score, Tegner activity score, and Telos stress test (Telos, Weiterstadt, Germany). All of the patients were evaluated for TVE by computed tomography scanning at the 1-year follow-up; the results were compared with the data from 1 week postoperatively. A volume increment of more than 44%, which indicates 2 mm of widening of the tunnel diameter, was defined as TVE.

Results: The overall incidence of TVE after single-bundle PCL reconstruction was 3.6% (2 of 56 patients) for the femoral tunnel and 5.4% (3 of 56 patients) for the tibial tunnel. The overall mean tunnel difference between 1 week postoperatively and the final follow-up was 12.0% for the femoral tunnel and 10.6% for the tibial tunnel. The mean femoral TVE was 10.1% in group A and 13.8% in group B; the mean tibial TVE was 9.9% in group A and 11.2% in group B. These differences were not statistically significant. The functional outcome was improved in both groups, showing no statistical difference at the 1-year follow-up. Conclusions: The femoral and tibial TVE caused by single-bundle PCL reconstruction using the remnant bundle—preservation technique showed no significant differences between the Achilles allograft and the mixed graft over a short-term follow-up. Furthermore, the overall incidence of TVE in PCL reconstruction in this study was low. Level of Evidence: Level II, prospective comparative study.

The goal of posterior cruciate ligament (PCL) reconstruction is to restore the knee to more normal kinematics and prevent osteoarthritis.¹ PCL fibers tend to remain after injury; remnant PCL fibers are capable of spontaneous healing and, thereby, contributing to posterior stability and proprioception of the joint.² However, in contrast to anterior cruciate ligament (ACL) reconstruction, the clinical outcomes of PCL reconstruction—despite the variety of surgical techniques available and these potentialities notwithstanding—have been inconsistent and less satisfactory than those for the ACL.¹

Femoral and tibial tunnel volume enlargement (TVE) after ACL reconstruction is a well-studied and well-described phenomenon in the literature.³⁻⁸ Whereas the exact causes of TVE remain unknown, 2 major theories, though hotly debated, have been offered.⁵⁻⁹ First, biological factors include the use of allograft tissue, propagation of synovial fluid within a tunnel, and increased cytokine levels within the synovial fluid that induce osteolysis and, subsequently, tunnel...
widening (i.e., TVE). Second, mechanical factors include movement of the graft within the tunnel, fixation methods or devices, and acceleration of rehabilitation. TVE causes can hinder ACL reconstruction by altering the direction and anatomic insertion site of the graft within a joint, thereby reducing its functionality. However, the potentially adverse effects of femoral and tibial TVE on PCL reconstruction outcomes is not well documented.

The purpose of this study was to evaluate and compare femoral and tibial TVE after arthroscopic single-bundle PCL reconstruction by a remnant bundle—preservation technique using Achilles allograft and mixed graft. We hypothesized that (1) TVE, of either the femoral or tibial tunnel, would occur after PCL reconstruction, as has been the case after ACL reconstruction; (2) there would be a different degree of TVE with the use of Achilles allograft versus mixed graft; and (3) TVE would not correlate with clinical outcomes.

**Methods**

**Patient Selection**

All patients who had undergone arthroscopic primary PCL reconstruction with Achilles allograft or mixed graft (tibialis anterior allograft plus hamstring tendon autograft) with a double-fixation method (bioabsorbable interference screw and post-tie reinforcement) for PCL rupture at a single institution between 2007 and 2011 were eligible for enrollment in this prospective study. The inclusion criteria were unilateral isolated PCL rupture, age 18 to 40 years, a normal contralateral knee, and informed consent by the patient for participation. Patients with an associated meniscal injury also were included in the study. The exclusion criteria were concomitant ligament injury, concomitant fracture including avulsion fracture, previous meniscectomy, previous failed PCL reconstruction, and less than 1 year of follow-up postoperatively. Ultimately, Achilles allograft patients were assigned to group A (including 3 cases of meniscal injury), and patients who had received the mixed graft were assigned to group B (including 2 cases of meniscal injury). The study was approved by the institutional review board of the hospital.

A total of 86 patients underwent the procedure during the study period, and 78 patients agreed to participate in the study. On the basis of the pertinent criteria, 9 of these 78 individuals were excluded from the study: 5 with an associated ligament injury, one with an avulsion fracture, one with a concomitant tibial condylar fracture, and 2 who had had surgery previously. Therefore, 69 patients who had undergone arthroscopic single-bundle PCL reconstruction by the remnant-preservation technique were enrolled. Subsequently, 13 patients dropped out of the study: 8 were lost to follow-up, and 5 refused to undergo follow-up computed tomography (CT). Accordingly, the final analysis included data from 56 patients, and we have divided the patients into 2 groups based on their respective graft selection after providing an explanation of the advantages and disadvantages of harvesting hamstring tendon: group A received Achilles allograft (n = 27), and group B received mixed graft (n = 29) (Fig 1).

A single senior surgeon performed the procedure in all patients in both groups. The surgical indications for PCL reconstruction were (1) posterior translation of grade III or more compared with the uninjured contralateral knee and (2) failure of 3 months of nonoperative treatment. Nonoperative treatment included a vigorous quadriceps strengthening program that was begun as the patient’s symptoms allowed, closed-chain exercises such as squats and leg presses, and hamstring muscle strengthening initiated 6 weeks after injury.

**Surgical Technique**

**Graft Preparation.** To prepare the mixed graft (tibialis anterior allograft and hamstring tendon autograft), the semitendinosus and gracilis tendons were harvested in the routine fashion and each harvested hamstring tendon plus the tibialis anterior allograft tendon was prepared with a total length of approximately 24 to 26 cm. Suturing at each end of the 2-stranded hamstring autograft and tibialis anterior allograft was performed with No. 5 Ethibond (Ethicon, Somerville, NJ) with a running baseball stitch technique. The resultant graft had a diameter of 9 to 10 mm and a length of approximately 17 to 18 cm. For preparation of the Achilles allograft, a calcaneal bone plug was removed and the insertion part of the tendon preserved. The end of the tendon was sutured, again using No. 5 Ethibond.
Ethibond with the running baseball stitch technique. The resultant graft had a diameter of 9 to 10 mm, and the total graft length was approximately 14 to 15 cm, with a proximal 3 cm for the femoral tunnel, 5 cm for the intra-articular portion, and 6 to 7 cm for the tibial tunnel.

**Arthroscopic Portals.** A total of 5 portals were routinely formed: the standard anteromedial and anterolateral portals and the posteromedial, posterolateral, and posterior trans-septal portals. First, an arthroscopic posteromedial portal was made; then, under direct arthroscopic visualization through the posteromedial portal, a trans-septal portal was formed at the posterior septum just behind the remnant PCL to reach the posterolateral compartment. Thus the posterolateral portal was formed under direct arthroscopic visualization. By use of this trans-septal portal, the PCL tibial attachment site could be completely exposed by detaching the posterior capsule from the PCL more than 10 mm downward from the articular surface.\(^1\)

**Tibial Tunnel Preparation.** The PCL tibial guide (Linvatec, Largo, FL) was set to 55°, and the hook of the PCL drill guide was introduced through the anteromedial portal; then, under direct arthroscopic visualization, the drill guide was advanced to the distal-lateral aspect of the PCL tibial attachment. With the knee flexed at 90°, a guide pin was introduced and exited the posterior tibial cortex approximately 15 mm inferior to the tibial plateau. Care was taken to avoid over-inserting the guide pin and possibly injuring the posterior neurovascular structures. On the basis of measurements provided by the graft sizer, a matched diameter of tibial tunnel was reamed.

**Femoral Tunnel Preparation.** A 3- to 4-cm longitudinal skin incision was performed along the medial border of the vastus medialis muscle at the level of the medial condyle. After dissection of the soft tissue, the tunnel entrance was marked on the medial femoral condyle. The femoral tunnel was then made by use of an outside-in technique to avoid formation of an acute angle between the tunnel and the intra-articular portion of the graft. A guidewire was inserted, by which the femoral tunnel was reamed. The center of the femoral tunnel was positioned 7 mm proximal to the margin of the articular cartilage of the medial femoral condyle, at the 11-o’clock position in the left knee joint or the 1-o’clock position in the right knee joint. A femoral tunnel 30-mm deep, with a diameter that was the same as that of the graft, was formed.

**Graft Fixation.** A wire passer was introduced from the tibial tunnel and was passed through the posterior compartment to the anterior compartment and then to the femoral tunnel. The graft attached to it was then pulled down through the femoral tunnel and onward through the tibial tunnel. The femoral-side fixation of the mixed graft and Achilles allograft was seated in the femoral tunnel by use of a double-fixation method involving a 10 × 30-mm bioabsorbable interference screw (Smith & Nephew, Mansfield, MA) and post-tie reinforcement in the form of a 6.5-mm cancellous screw and washer. The absorbable or metal interference screws were situated anterior to the graft by the outside-in technique. For the reduced position, the knee was held in 90° of flexion with an anterior drawer force to re-create a normal step-off between the medial femoral condyle and the tibial plateau; to confirm the reduction state of the knee joint, the tension of the ACL in the reduced position was evaluated with a probe. Subsequently, with the knee in the reduced position, the tibial side of both grafts was fixed, again by double fixation with a bioabsorbable interference screw and post-tie reinforcement.

**Postoperative Rehabilitation**

The patients in both groups followed an identical postoperative rehabilitation regimen. The affected knee was maintained in full extension in a brace for 4 weeks. A straight leg—raising exercise was initiated on the third postoperative day. Partial weight bearing with crutches was begun 2 weeks after surgery and continued for 4 weeks. Six to eight weeks after surgery, passive knee flexion exercises in the prone position were begun to minimize the hamstring activation and regain full range of motion. Closed—kinetic chain exercises were delayed until 3 months postoperatively to avoid excessive posterior stress on the graft. The patients generally returned to normal activities 6 to 9 months after surgery.

**CT Evaluation**

A noncontrast CT scan of the operative knee in the supine position was performed with a spiral CT scan system (Somatom Emotion 6; Siemens, Berlin, Germany). The CT images were acquired at 120 kV and 75 mA, with a slice thickness of 2 mm and 0.5-mm collimation. Scans were performed 1 week and 1 year postoperatively. The area was measured and the volume was calculated by 2 orthopaedic surgeons blinded to the group to which the patient was allotted. To measure the tunnel volume, a series of CT cross-sectional images was obtained for each tunnel. The femoral and tibial tunnels were identified on the coronal and axial images, respectively, because these images showed the highest agreement between the observers. The cross-sectional area of each tunnel on each image was estimated with a digitized image—archiving and communication system (M-view 5.4; Marotech, Seoul, South Korea) (Fig 2).
The area on each image was totaled and multiplied by the slice thickness to calculate the total volumes of the femoral and tibial tunnels. The tunnel volume 1 week postoperatively was used as the baseline measurement for comparison with the 1-year follow-up result. TVE was defined as a volume increase greater than 44%, corresponding to a 2-mm increase in diameter. It was then classified into 2 categories according to its presence or absence.

Clinical Assessment
All of the patients were functionally assessed on the basis of the International Knee Documentation Committee (IKDC) score, Lysholm score, and Tegner activity score both preoperatively (on admission) and postoperatively (at the 1-week and 1-year follow-up visits). Posterior knee laxity likewise was quantitatively measured both preoperatively and postoperatively by use of the Telos stress radiographic unit (Telos, Weiterstadt, Germany) at 90° of knee flexion with a 20-N posterior load applied to the proximal tibia, and the side-to-side difference was used to determine the degree of laxity.

Statistical Analysis
Before the commencement of the study, a power analysis was performed to determine the sample size. For power of 0.8 and an \( \alpha \) value of .05, the sample size required was 26 patients per group. This study’s results have a power of 0.81, for 27 patients in group A and 29 in group B. TVE was defined as a volume increase greater than 44% that corresponds to a 2-mm increase in diameter, which we considered a clinically significant difference. To compare follow-up and age differences between the 2 groups, we used the independent \( t \) test; for the sex difference, we used the Fisher exact test. The intraobserver and interobserver reliabilities were analyzed by interclass and intraclass correlation coefficients. Preoperative and postoperative comparisons of the Lysholm knee score, Tegner activity score, and Telos stress test were carried out with the Wilcoxon rank sum test. The 2 graft materials were compared by use of the Mann-Whitney \( U \) test. Statistical analysis was performed with SPSS software (version 18.0; SPSS, Chicago, IL); \( P < .05 \) was considered significant.

Results
Group A comprised 22 male and 5 female patients with a mean age of 30.6 years (range, 20 to 39 years) who were followed up for a mean period of 22.1 months (range, 12 to 38 months); group B comprised 22 male and 7 female patients with a mean age of 29.0 years (range, 19 to 40 years) who were followed up for a mean period of 21.2 months (range, 12 to 60 months). There were no significant differences between the 2 groups in mean follow-up period (\( P = .81 \)), mean age at the time of surgery (\( P = .43 \)), or sex ratio (\( P = .40 \)).

CT Measurements
The interclass and intraclass correlation coefficients ranged from 0.85 to 0.93 and from 0.89 to 0.94, respectively, indicating a significantly high agreement between the 2 observers. The overall incidence of TVE after PCL reconstruction was 3.6% (2 of 56 patients) for the femoral tunnel and 5.4% (3 of 56 patients) for the tibial tunnel (Fig 3). The overall postoperative mean

Fig 2. Method for measurement of tunnel volumes on (A) coronal image for femoral tunnel and (B) axial image for tibial tunnel.
tunnel volume difference between the 1-week and 1-year follow-up visits was 12.0% for the femoral tunnel and 10.6% for the tibial tunnel. The mean initial CT tunnel volumes for the femoral and tibial tunnels and at follow-up are shown in Table 1. At the 1-year follow-up, the mean increment of femoral tunnel volume was 10.1% in group A and 13.8% in group B; the mean increment of tibial tunnel volume, meanwhile, was 9.9% in group A and 11.2% in group B. The mean TVE of the femoral and tibial tunnels showed no statistical differences between the 2 groups (\(P = .14\) for femoral tunnel and \(P = .73\) for tibial tunnel). Similarly, there was no statistical difference in the mean femoral and tibial tunnel volumes at the 1-year follow-up between the 2 groups (\(P = .25\) for femoral tunnel and \(P = .32\) for tibial tunnel) (Table 1, Figs 4 and 5).

**Clinical Results**

The functional outcomes at the 1-year follow-up were analyzed. The preoperative and final follow-up Lysholm score, IKDC subjective score, Tegner activity score, and side-to-side difference on Telos stress test are shown in Table 2. There were no significant differences in functional outcomes between the 2 groups at the 1-year follow-up \((P = .28\) for Lysholm score, \(P = .19\) for IKDC score, and \(P = .86\) for Tegner activity score). Moreover, there was no significant difference in posterior laxity on Telos stress test between the groups \((P = .16)\) (Table 2).

**Discussion**

The most important findings of this study are as follows: (1) the mean bone tunnel volume after PCL reconstruction showed no statistically significant differences at the 1-year follow-up between the 2 groups \((P = .72)\); (2) TVE was not observed as frequently as in cases of ACL reconstruction, and (3) there were no significant differences in TVE between the groups. TVE after ACL reconstruction is a well-known and adverse phenomenon, although its mechanism has yet to be elucidated. The reported incidences of TVE range from

![Fig 3. CT images of femoral and tibial tunnel enlargement on sagittal images. (A) 1 week postoperatively and (B) 1 year postoperatively.](image)
30.1% to 100.4% for the femoral tunnel and from 20.9% to 73.9% for the tibial tunnel. The many studies that have investigated TVE timelines in patients undergoing ACL reconstruction agree that TVE occurs within the first year after the operation and shows no further progression 2 to 3 years thereafter. A minimum 1-year follow-up evaluation period seems ideal for assessment of TVE.

Several biological and mechanical factors contributing to TVE have been suggested. Among the biological factors, one of the proposed theories is that the use of allograft tissue induces an immune response from the host. Fahey and Indelicato reported a TVE comparison of patellar tendon allograft with patellar tendon autograft fixed with press fitting on the femoral side and...
with interference screws on the tibial side, finding a significantly increased incidence of TVE in the allograft group. Our TVE results showed no statistical difference between the Achilles allograft group and the mixed graft group. Webster et al.,\textsuperscript{22} comparing TVE incidences between patellar tendon and hamstring grafts, found a higher incidence in the hamstring group, which suggests that the bone-to-tendon interface, along with fixation distant from the joint line, might contribute to graft micromotion that exacerbates TVE. In our study

Table 2. Clinical and Functional Outcomes for Groups A and B Preoperatively and at 1-Year Follow-up

<table>
<thead>
<tr>
<th>Examination</th>
<th>Group A: Achilles Allograft</th>
<th>Group B: Mixed Graft</th>
<th>P Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preoperative\textsuperscript{1}</td>
<td>1-yr Follow-up\textsuperscript{1}</td>
<td>Preoperative\textsuperscript{1}</td>
</tr>
<tr>
<td>Lysholm score</td>
<td>44.78 ± 6.85</td>
<td>90.47 ± 4.49</td>
<td>48.0 ± 7.28</td>
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<tr>
<td>IKDC score</td>
<td>48.21 ± 9.42</td>
<td>83.87 ± 5.46</td>
<td>44.8 ± 8.27</td>
</tr>
<tr>
<td>Tegner score</td>
<td>2.57 ± 0.94</td>
<td>6.04 ± 1.74</td>
<td>2.36 ± 0.81</td>
</tr>
<tr>
<td>Posterior laxity (mm)</td>
<td>12.30 ± 1.82</td>
<td>3.0 ± 1.73</td>
<td>12.8 ± 2.12</td>
</tr>
</tbody>
</table>

\*P < .05 was considered significant.
\textsuperscript{1}The clinical results within group A showed a statistical improvement (P < .05).
\textsuperscript{2}The clinical results within group B showed a statistical improvement (P < .05).
there was no difference between the grafts, and the overall incidence of TVE was much lower than previously reported for ACL reconstruction, although the bone-to-bone interface was not formed.

Another suggested biological factor affecting TVE is the use of bioabsorbable interference screws that can cause local inflammatory responses, resulting in cell necrosis that leads to TVE. In their CT-based study of TVE after ACL reconstruction, reported a higher TVE incidence for cases of interference screw fixation. However, in our study, our use of interference screws notwithstanding, the results for post-PCL reconstruction were different.

The most accepted mechanical factor is graft motion at the graft-tunnel interface. However, a review of the relevant previously published studies suggests that TVE occurs after ACL reconstruction regardless of the graft type, fixation method, or fixation device, which might result from the failure to re-create a normal graft attachment despite improvements in surgical techniques. In PCL reconstruction the tibial tunnel tends to be longer than in ACL reconstruction; correspondingly, there is a longer distance from the joint line, affecting increased graft motion, known as the windshield-wiper effect. However, our results showed no significant TVE in either group, despite the longer tibial tunnel.

Another suggested mechanical factor is postoperative accelerated rehabilitation, which can increase stresses on the graft in advance of graft-tunnel incorporation, leading to graft motion within the tunnel and resulting in TVE. Our postoperative rehabilitation regimen involved 4 weeks’ stabilization of the knee in full extension and initiation of exercises 6 to 8 weeks after surgery to regain the full range of motion. Indeed, recent studies have emphasized the importance of rehabilitation for better clinical outcomes after PCL reconstruction. We assume that delayed rather than accelerated postoperative rehabilitation might have contributed to our post—PCL reconstruction results.

In summary, we considered the widely accepted potential TVE mechanisms in ACL reconstruction when analyzing the results of PCL reconstruction in our study. We hypothesize that a higher tendon healing potential and delayed postoperative rehabilitation can reduce the incidence and degree of TVE after PCL reconstruction.

Limitations

In this prospective study, we maintained treatment consistency between the groups to the extent possible: one senior surgeon, one fixation method, and an identical postoperative rehabilitation regimen. There are, nonetheless, several possible limitations. The first is the short-term follow-up and the loss of follow-up for CT scan analysis and clinical outcomes, from which different results might have been derived if the follow-up had been longer. The second limitation is the time point at which the CT scans were performed, which could be an important factor influencing the results. However, as noted earlier, there is a general consensus that TVE develops mostly within the first year of surgery, despite a report showing no significant change between 4 months and 2 years. The third limitation is the fact that TVE based on fixation method type was not considered. The fourth limitation is the fact that because the allograft was used in both groups, the properties of the grafts in each group may not respond differently, which may affect the results. The final limitation is that changes in the incidence and degree of TVE over midterm and long-term follow-up remain unknown.

Conclusions

The femoral and tibial TVE caused by single-bundle PCL reconstruction using the remnant bundle—preservation technique showed no significant differences between the Achilles allograft and the mixed graft over a short-term follow-up. Furthermore, the overall incidence of TVE in PCL reconstruction in this study was low.

References


