Clinical Comparison of Conventional and Remnant-Preserving Transtibial Single-Bundle Posterior Cruciate Ligament Reconstruction Combined With Posterolateral Corner Reconstruction

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Clinical Comparison of Conventional and Remnant-Preserving Transtibial Single-Bundle Posterior Cruciate Ligament Reconstruction Combined With Posterolateral Corner Reconstruction

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Background: Despite persistent continuity of the attenuated posterior cruciate ligament (PCL) in most PCL insufficient knees, few reconstruction techniques that preserve the PCL remnant have been presented. Furthermore, data regarding the clinical outcomes of these approaches are even more limited, and the clinical validity of remnant preservation has not yet been established.

Purpose: To compare the clinical outcomes of transtibial PCL reconstructions that incorporate remnant preservation with conventional techniques (in which remnant preservation is not performed).

Study Design: Cohort study; Level of evidence 3.

Methods: The authors retrospectively evaluated 53 cases of PCL reconstruction with simultaneous posterolateral corner reconstruction. Of these, 23 were performed with a conventional approach without remnant preservation (group C), and 30 incorporated a remnant-preserving technique (group R). In all cases, the minimum follow-up period was 24 months. Each patient was evaluated using the following variables: Lysholm knee score, Tegner activity scale, return to activity, International Knee Documentation Committee (IKDC) knee score and grade, and degree of posterior laxity on stress radiograph.

Results: The mean side-to-side differences in posterior tibial translation, Lysholm knee score, return to activity, and objective IKDC grade were similar between group C (4.4 ± 3.0 mm; 82.6 ± 11.0; 21.7%; A and B: 73.9%) and group R (4.1 ± 3.4 mm; 84.1 ± 10.7; 26.7%; A and B: 83.3%; P = .761, .611, .679, .755). However, the final Tegner activity scale, near–return to activity, and subjective IKDC score differed significantly between group C (3.5 ± 0.8; 43.5%; 64.5 ± 8.8) and group R (4.3 ± 1.1; 73.3%; 70.6 ± 7.9; P = .007, .028, .012).

Conclusion: Techniques combining remnant-preserving transtibial single-bundle PCL reconstruction with posterolateral corner reconstruction resulted in somewhat better activity-related outcomes compared with those of approaches without remnant preservation. However, incorporation of remnant preservation does not appear to provide increased posterior stability or result in clinically superior outcomes versus those of techniques without remnant preservation.

Keywords: knee; posterior cruciate ligament; reconstruction; remnant preservation

The posterior cruciate ligament (PCL) is the primary restraint to posterior tibial translation and is the largest and strongest ligament in the knee. Various surgical techniques and graft choices for PCL reconstructions have been introduced in an attempt to improve the functional outcome of surgical treatment and to try to restore normal knee kinematics. The superiority of the transtibial versus the tibial inlay technique, single- versus double-bundle reconstructions, or the 1- versus 2-incision technique have not been definitively established.[31]

Recent studies have demonstrated that the success of anterior cruciate ligament (ACL) reconstruction may depend not only on the stability of the reconstruction but also on the recovery of proprioception after the operation.[6,13,15] Knee ligaments including the PCL have been shown to contain mechanoreceptors that provide the

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central nervous system with information regarding joint position sense, balance, and joint movement.[23,35,38] Without this neural feedback mechanism, the success of knee ligament reconstructions may be less than optimal.

Because of better blood supply, PCL injuries have better healing potential, and intact PCL remnants are often observed on preoperative magnetic resonance imaging (MRI) scans and at the time of surgery.[31,37,42] In an attempt to improve the functional outcome of PCL surgery, some authors have described surgical techniques that preserve any remaining intact PCL fibers.[2,3,25,39,43] However, there is still controversy regarding whether preserving any intact PCL fibers leads to a better clinical outcome. The purpose of this retrospective, case-controlled clinical study was to compare the clinical outcomes of patients undergoing a conventional single-bundle transtibial PCL reconstruction to those of patients undergoing a single-bundle, transtibial PCL reconstruction with preservation of intact PCL fibers. It is our hypothesis that the results of the remnant-preserving technique will be superior to the conventional technique in which all PCL fibers are removed.

MATERIALS AND METHODS

After institutional review board approval, we reviewed the records of 168 patients, all of whom underwent PCL reconstruction between January 2002 and September 2007. Notably, all patients were treated by the senior author (S.-J.K.). Because of a lack of patients with isolated PCL injuries, the study population consisted of patients with combined PCL and posterolateral corner injuries. The inclusion criteria for the study consisted of patients who were undergoing a transtibial single-bundle PCL reconstruction using an Achilles tendon allograft with simultaneous reconstruction of the posterolateral corner.[28] Exclusion criteria included patients with (1) isolated PCL reconstructions, (2) other PCL or posterolateral reconstructions (eg, double-bundle PCL reconstructions, reconstructions using the inlay technique, biceps tenodesis, and miscellaneous), (3) bilateral or concomitant ligament injuries (ACL ruptures or medial collateral ligament injuries) except posterolateral rotatory instability (PLRI), (4) grade III or higher chondral lesions as assessed by the Outerbridge classification system,[8,32] (5) subtotal or total meniscectomies, (6) revisional reconstructions, (7) additional comorbid fractures, and (8) follow-up durations of less than 24 months. Using these criteria, a total of 53 patients were enrolled in the study. Group C consisted of 23 patients who underwent conventional transtibial single-bundle PCL reconstruction between January 2002 and June 2007. In the group C patients, any PCL remnants were removed. Group R consisted of 30 patients who underwent transtibial single-bundle PCL reconstruction between May 2004 and September 2007. In the group R patients, the intact PCL remnant was preserved. All patients in both groups had PCL remnant tissue bridging the femur and tibia regardless of whether the tissue was robust or attenuated, except 3 patients in group C, in whose arthroscopic findings only an atrophic stump was identified.

Indications for Surgery

Indications for surgery included posterior laxity of grade 2 or higher, as determined by the difference in posterior tibial translation of the affected knee versus that of the normal contralateral knee on posterior stress radiography (grade 1 is defined as <5 mm, grade 2 as 5-10 mm, and grade 3 as >10 mm); concomitant PLRI on the reverse pivot shift test; a difference in external rotation laxity greater than 10° between knees, as assessed by the Dial test at 30° and 90° of knee flexion; 3 mm or more of increased varus gap of the affected knee compared with the normal contralateral knee on varus stress radiography; and pain and/or instability with associated functional deficits.

Surgical Procedure

Anterolateral Transtibial Single-Bundle PCL Reconstruction With or Without Ligament Remnant Preservation. An Achilles tendon-bone allograft was used as graft material in all patients. Bone plugs measuring 11 mm in width and 25 mm in length were harvested along with the attached Achilles tendon using an oscillating saw. The tendinous part of the graft measured 60 mm in length and 11 mm in width. The tendinous end of the Achilles tendon was whipstitched over a distance of 30 mm, and 9 mm EndoPearl (Linvatec, Largo, Florida) was attached to the end of the tendon.

To more conveniently reconstruct the PCL, 3 unique portals were used: a high medial parapatellar portal, a far anterolateral portal, and a high posteromedial portal.[27] The high medial parapatellar portal was made first at the highest position on the medial parapatellar line, which is just off the medial edge of the patellar tendon and the inferior border of the patella. This portal is more proximal than the conventional anteromedial portal and facilitates access to the attachment area of the PCL through the intercondylar notch as well as to the posterior capsule with a 30° arthroscope. The far anterolateral portal was made just above the joint line and 5 mm anterior to the lateral femoral condyle. Then, under direct visualization through the high medial parapatellar portal, the high posteromedial portal was made. In the remnant-preserving technique, the tibial insertion of the PCL remnant was peeled laterally from the PCL tibial insertion site using a narrow osteotome that was introduced through the high posteromedial portal, exposing an exit site for the PCL tibial guide pin (Figure 1). The tip of the PCL guide was positioned in the PCL fossa approximately 1.5 cm below the articular surface of the medial joint line, slightly lateral to the center of the PCL tibial insertion site. A longitudinal 3- to 4-cm skin incision was then made just lateral of the tibial tuberosity so that the tibialis anterior muscle could be stripped and retracted laterally, exposing the starting point for the tibial tunnel approximately 2 cm lateral to the tibial crest. Using the high posteromedial portal for viewing purposes, the surgeon visualized the guide pin to penetrate the ideal site of the PCL footprint. Next, the tibial tunnel was sequentially reamed using a cannulated reamer to a final diameter of 11 mm. The final pass of tibial tunnel reaming was performed manually to avoid damage to the posterior neurovascular

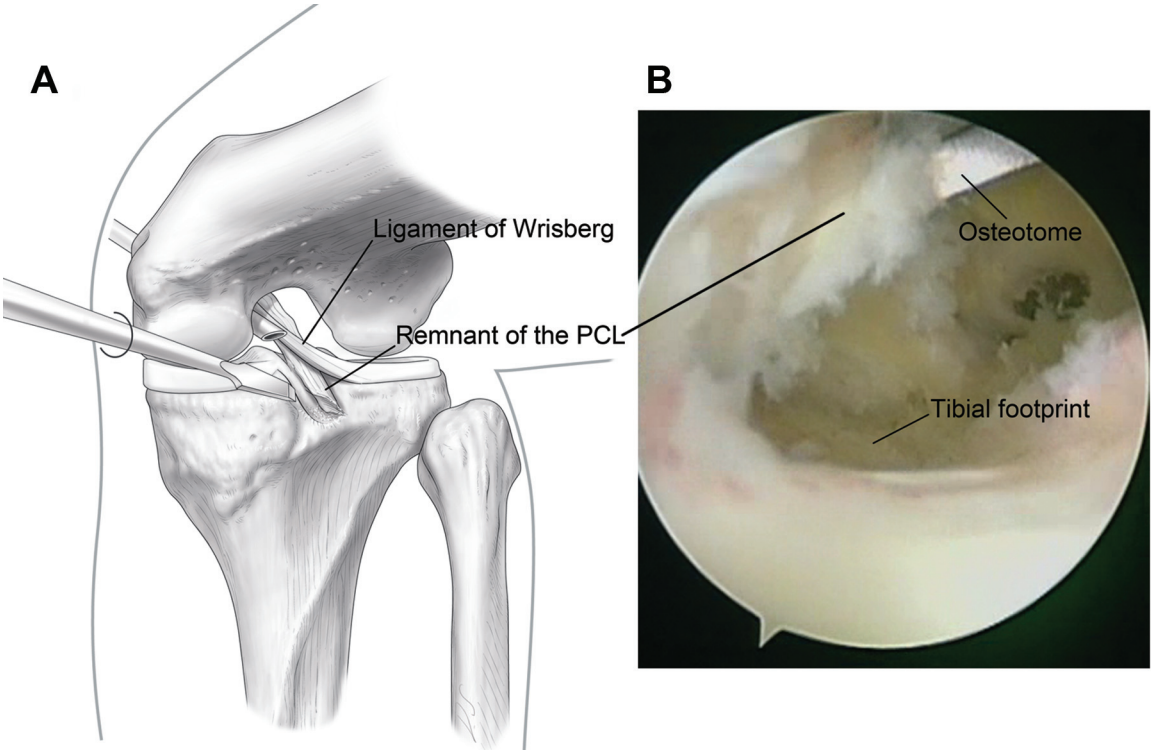

Figure 1. (A) The remnant of the posterior cruciate ligament (PCL) is laterally peeled from the tibial attachment with a narrow osteotome. (B) Arthroscopic view through the high medial parapatellar portal.

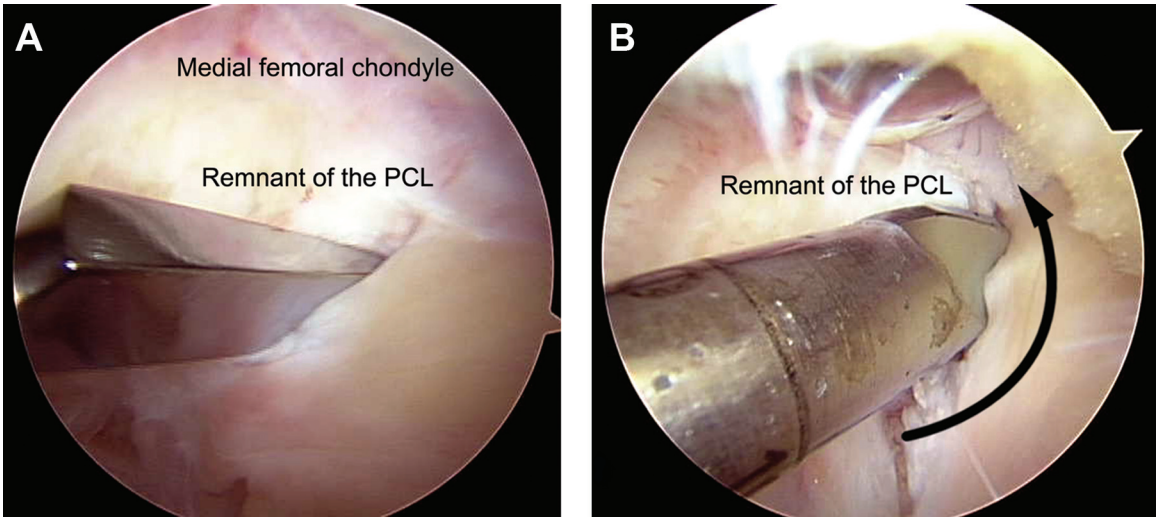

Figure 2. (A) Arthroscopic view through the high medial parapatellar portal. The site of the femoral socket is prepared with an osteotome in the center of the anterolateral bundle footprint along the fiber direction. (B) Arthroscopic view through the high medial parapatellar portal. The reamer was rotated counterclockwise to preserve as much of the posterior cruciate ligament (PCL) remnant as possible and to allow for socket positioning in the intended location.

structures. The femoral socket landmark in the center of the anterolateral bundle footprint was carefully prepared with a blade and osteotome to avoid any damage to the remnant (Figure 2A). The femoral socket center was placed 8 mm posterior to the articular junction and at a 10:30-o'clock (in the left knee) or 1:30-o'clock (in the right knee) position. A cannulated headed reamer with a plastic sheath was then introduced via the far anterolateral portal. To reduce graft-socket divergence in the femur, the following techniques were used: (1) the knee was maintained in a flexed position of greater than 100°, (2) the proximal tibia was pushed posteriorly as much as possible, and (3) the cannulated headed

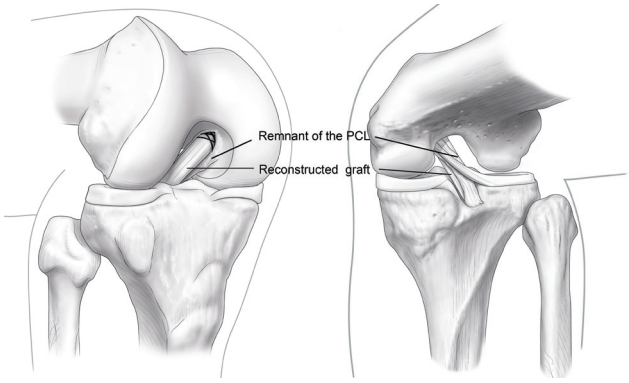

Figure 3. Illustrations of single-bundle posterior cruciate ligament (PCL) reconstruction with remnant preservation.

reamer was introduced through the far anterolateral portal with a plastic sheath and maneuvered posteriorly to remain in contact with the lateral femoral condyle. The reamer was rotated in a counterclockwise manner to preserve as much of the PCL remnant as possible, as well as to facilitate socket creation in the intended location (Figure 2B). In this way, the femoral socket was prepared to a depth of 35 mm, and the edge of the femoral socket (particularly the posterior half) was chamfered to reduce graft abrasion at the femoral socket aperture. Femoral fixation was performed with an absorbable interference screw via the far anterolateral portal while the knee remained in 100° of flexion. The knee was then passively manipulated through 20 extension-flexion cycles, during which time traction was applied distal to the graft. The distal bone peg was also secured by an absorbable interference screw while the knee remained in 70° of flexion. At this time, an anteriorly directed force was also continuously applied to maintain a normal anterior tibial step-off (Figure 3). For conventional PCL reconstruction procedures, the same protocol as described above was performed, although all remnants were removed.

Anatomic Posterolateral Corner Reconstruction of the Lateral Collateral Ligament and Popliteus Tendon Using Tibialis Posterior Tendon Allograft. A skin incision was made on the lateral aspect of the knee immediately anterior to the fibular head and extended proximally to the lateral femoral epicondyle in an extended position. The interval between the iliotibial tract and the biceps tendon was dissected. Using an ACL guide, the tip of the guide was placed 10 mm inferior to the posterior joint line and 5 mm medial to the posterior aspect of the tibiofibular joint, while the anterior portion was placed on the Gerdy tubercle. A guide pin was then inserted under fluoroscopic guidance, and a tunnel was created with a 7-mm diameter cannulated reamer. In a similar fashion, the tip of the ACL guide was placed immediately posteromedial to the lateral collateral ligament (LCL) of the fibular head, and the other end was placed at the anteroinferior aspect of the fibular head 10 mm above the peroneal nerve. The resulting tunnel was angled 70° to the axial plane in an anteroinferior to posterosuperior direction. The reamer was rotated in a counterclockwise fashion to avoid any cortical destruction of the fibular head or peroneal nerve injury.

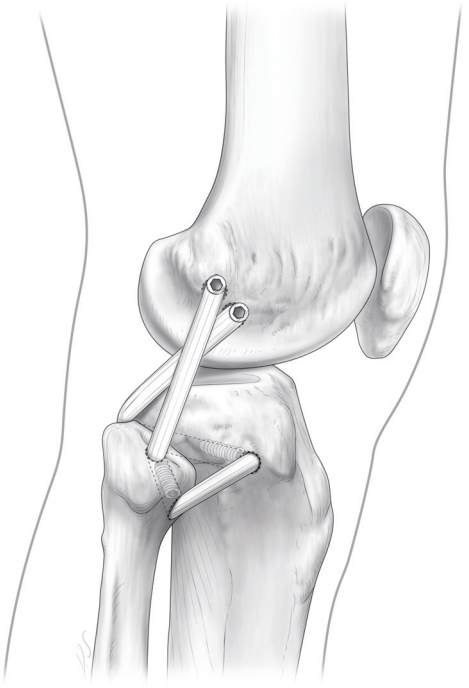

Figure 4. An illustration of posterolateral corner reconstruction of the lateral collateral ligament and the popliteus tendon with a tibialis posterior tendon allograft.

At one end of the allogenic tibialis tendon, a No. 2 Ethibond suture (Ethicon, Somerville, New Jersey) was whip-stitched for approximately 25 mm, and then a 7-mm diameter EndoPearl device was attached to the other end. With a looped wire, the leading suture of the graft was pulled anteriorly through the tibial tunnel. Next, the graft was passed posteriorly through the fibular tunnel using the same method. The graft was then fixed in both tibial and fibular tunnels by bioabsorbable interference screws through the anterior aperture. A popliteus tendon (PT) insertion site was placed at the superior margin of the anterior third of the popliteal sulcus, located about 15 mm distal to the femoral epicondyle. An LCL insertion site was also placed at the anterosuperior lateral femoral epicondyle, with isometry defined and confirmed by a migration of less than 2 mm during knee flexion and extension. A cannulated reamer 7 mm in diameter was used to create femoral sockets measuring 40 mm in depth in the anterosuperior direction to the transverse line of the femoral shaft at an angle of 20° for the PT socket and LCL socket, respectively. Each end of the graft was pulled through the femoral socket and then fixed using a bioabsorbable interference screw (Figure 4).

Postoperative Rehabilitation

All patients underwent the same rehabilitation protocol. The reconstructed graft was protected by immobilization with knee extension for the first 4 weeks. During this

time, patients wore a hinged knee brace 24 hours a day and performed protected range of motion exercises 3 times a day. Isometric quadriceps strengthening and patella mobilization exercises were also initiated immediately after surgery. During these first 4 weeks, toe-touch weightbearing was also permitted. After this period, weightbearing and knee flexion were allowed as tolerated, with flexion progressively increased to a goal of 90°. By 8 weeks, the brace was removed, and a closed chain kinetic exercise program was started. By weeks 10 to 12, stationary bicycle, stair-stepping, and single-leg exercises were permitted, while full knee flexion and squatting were permitted after week 12. At 4 to 5 months, swimming and aqua jogging were allowed. Finally, patients were permitted to resume sports and activities involving jumping, pivoting, and sidestepping after 6 months.

Clinical Assessments

Postoperatively, patients were regularly followed up in outpatient clinic visits at 2 weeks, 3 months, 6 months, and then annually. Clinical assessments were performed before surgery and at the final follow-up. All manual examinations were performed by the senior author and another orthopaedic surgeon. All stress radiographs were evaluated by 2 trained orthopaedic surgeons, both of whom were blinded to the clinical findings. From these assessments, the averages of the 2 individual values were used to determine the final side-to-side differences (SSD). Both posterior tibial translation and varus laxity were quantified according to stress radiography using a Telos device (Telos GmbH, Marburg, Germany) with a load of 150 N at 90° and 30° of knee flexion, respectively. In analyzing the stress radiographs, the peripheral bony landmarks in the femoral and tibial condyles as described by Jacobsen[22] were used and measured via the PACS system (Centricity PACS, GE Medical System Information Technologies, Milwaukee, Wisconsin). To determine the degree of external rotation on the Dial test, the angle between the axis of the medial border of the foot and the thigh was measured at 30° and 90° of knee flexion. All range of motion (ROM) measurements were assessed using a goniometer. To enhance the reliability of measurements, interobserver variability was adjusted for by calculating the mean of 2 values assessed by different observers. Functional status was assessed using the Lysholm knee scoring scale,[41] the Tegner activity scale,[41] and the International Knee Documentation Committee (IKDC) subjective and examination form.[44] We defined 2 kinds of return to activity: patients who regained their preinjury activity level according to the Tegner activity scale at the final follow-up visit were considered as having accomplished return to activity, and those who regained their preinjury activity level or just 1 level below according to the Tegner activity scale at the final follow-up visit were considered as accomplishing near–return to activity.

Statistical Analysis

To compare preoperative clinical characteristics and postoperative outcomes between groups, the 2-sample t test was used for continuous or ranked variables satisfying the normality assumption, while the Mann-Whitney U test was used for nonnormally distributed variables. Either the chi-square test or Fisher exact test was used to compare categorical data.

In addition to bivariate analyses, multiple linear regression models for numerical variables (the SSD of posterior translation, Lysholm knee score, Tegner activity scale, and IKDC subjective score) were applied to adjust for potential compounding effects, while a multiple logistic regression model was similarly used for dichotomous variables (the near–return to activity and IKDC objective grade). Age, sex, elapsed time from injury to operation (with acute or subacute defined as less than 6 months, and chronic as greater than 6 months), preoperative posterior translation SSD, preoperative Lysholm knee score, preinjury Tegner activity scale, preoperative IKDC subjective score, preoperative IKDC objective grade, and surgical procedure (remnant preserving or not) were included as independent variables for these multivariate analyses. Interobserver reliability laxity measurements for both stress radiography evaluations and the Dial test were evaluated using an intraclass correlation coefficient (ICC) with a confidence interval of 95%. All values are presented as mean ± standard deviation (SD). Statistical analysis was performed using PASW software (version 17.0; SPSS Inc, Chicago, Illinois), with significance defined as $P < .05$.

RESULTS

Patient Demographics

The conventional reconstruction group (group C) was composed of 23 cases (18 male and 5 female patients), while the remnant-preserving reconstruction group (group R) consisted of 30 cases (27 male and 3 female patients). The mean patient age at the time of surgery was 39.4 years (range, 14-62 years) in group C and 38.0 years (range, 17-64 years) in group R. In group C, the underlying cause of the presenting knee injury was motor vehicle accidents in 12 cases (52.2%), sports injuries in 7 cases (30.4%), and accidental fall in 4 cases (17.4%). In group R, 17 cases (58.6%) resulted from motor vehicle accidents, 9 cases (30.0%) from sports injuries, and 4 cases (13.3%) from accidental falls. Associated meniscal injuries occurred in 5 patients in group C, including 4 cases with medial meniscal tears and 1 case with a lateral meniscal tear, while 6 cases with medial meniscal tears and 2 cases with lateral meniscal tears occurred in group R. The mean follow-up period was 48.8 months (range, 24-95 months) for group C and 44.7 months (range, 24-76 months) for group R (Table 1).

Ligament Stability

Preoperatively, no significant differences in ligament laxity were observed between the 2 groups. The mean SSD of posterior translation on stress radiographs was 12.0 ± 2.1 mm in group C and 12.8 ± 4.6 mm in group R (P = .414, ICC = 0.889). On varus stress radiography, the mean SSD of varus laxity was 4.6 ± 1.7 mm for group C

TABLE 1
Demographic Data for Patients

Variable	Group C (Conventional, n = 23)	Group R (Remnant Preserving, n = 30)	*P* Value
Age, y[a]	39.43 (14-62)	38 (17-64)	.726
Sex, male/female[b]	18 (78.3)/5 (21.7)	27 (90.0)/3 (10.0)	.272
Affected side, right/left[b]	10 (43.5)/13 (56.5)	14 (46.7)/16 (53.3)	.817
Duration from injury to operation, mo[a]	28.0 (1-156)	35.1 (1-240)	.878
Acute or subacute (≤6 months)[b]	9 (39.1)	9 (30)	.487
Chronic (>6 months)[b]	14 (60.9)	21 (70)	
Duration of follow-up, mo[a]	48.8 (24-95)	44.7 (24-76)	.829
Mechanism of injury[b]			
Motor vehicle accident	12 (52.2)	17 (56.6)	.930
Sports injury	7 (30.4)	9 (30.0)	
Accidental fall	4 (17.4)	4 (13.3)	

[a]The values are given as mean (range).
[b]The values are given as n (%).

TABLE 2
Preoperative Comparison of Clinical Variables Between Conventional and Remnant-Preserving Posterior Cruciate Ligament Reconstruction Group[a]

Variable	Group C (Conventional, n = 23)	Group R (Remnant Preserving, n = 30)	*P* Value	ICC (95% CI)
SSD of posterior translation, mm[b,c]	12.0 ± 2.1	12.8 ± 4.6	.414	0.889 (0.807-0.936)
SSD of varus gap, mm[b,c]	4.6 ± 1.7	4.6 ± 1.6	.965	0.830 (0.706-0.902)
SSD of Dial test at 30° of knee flexion, deg[b]	17.0 ± 3.3	16.3 ± 3.3	.770	0.562 (0.241-0.747)
SSD of Dial test at 90° of knee flexion, deg[b]	16.4 ± 3.3	17.0 ± 3.5	.547	0.639 (0.375-0.792)
SSD of range of motion, deg[b]	2.8 ± 5.6	2.6 ± 6.2	.720	0.845 (0.731-0.910)
Lysholm knee score[b]	58.7 ± 11.0	60.4 ± 8.9	.523	—
Preinjury Tegner activity scale[d]	5.0 (3-7)	5.3 (3-8)	.241	—
Preoperative Tegner activity scale[d]	2.2 (1-4)	2.4 (1-4)	.273	—
IKDC subjective score[b]	40.9 ± 8.7	41.6 ± 10.5	.772	—
Symptom[b]	18.4 ± 4.8	17.7 ± 5.0	.653	—
Sports[b]	14.0 ± 4.8	15.9 ± 5.7	.214	—
Function[b]	3.1 ± 1.9	2.5 ± 2.0	.282	—
IKDC objective grade[e]				
A	0	0	.799	—
B	0	0		
C	10 (43.5)	12 (40.0)		
D	13 (56.5)	18 (60.0)		

[a]SSD, side-to-side difference; IKDC, International Knee Documentation Committee; ICC, intraclass correlation coefficient; CI, confidence interval.
[b]The values are given as mean (standard deviation).
[c]As measured on stress radiographs made with use of the Telos device.
[d]The values are given as mean (range).
[e]The values are given as n (%).

and 4.6 ± 1.6 mm for group R (*P* = .965, ICC = 0.830). The Dial test at 30° and 90° of knee flexion compared with normal contralateral knee was 17.0° ± 3.3° and 16.4° ± 3.3° in group C, respectively, and 16.4° ± 3.3° and 17.0° ± 3.3° in group R, respectively (*P* = .770 and .547, ICC at 30° = 0.562 and ICC at 90° = 0.639) (Table 2).

At the final follow-up, the mean SSD in posterior translation on stress radiographs improved to 4.4 ± 3.0 mm in group C and 4.1 ± 3.4 mm in group R (*P* = .602, ICC = 0.897); the mean SSDs for varus laxity were 1.1 ± 0.9 mm and 1.2 ± 1.1 mm (*P* = .864, ICC = 0.827); and the mean Dial test scores at 30° and 90° of knee flexion were 4.6° ± 3.3° and 4.2° ± 3.4° in group C and 4.8° ± 3.5° and 4.9° ± 3.4° in group R (*P* = .805 and .269, ICC at 30° = 0.612 and ICC at 90° = 0.632), respectively. No significant differences were observed between the 2 groups for any of these parameters (Table 3).

Range of Motion

Preoperative examination showed the SSD of ROM was not significantly different (2.8° ± 5.6° in group C and

TABLE 3
Comparison of Clinical Variables Between Conventional and Remnant-Preserving Posterior Cruciate Ligament Reconstruction Group at the Final Follow-up[a]

Variable	Group C (Conventional, n = 23)	Group R (Remnant Preserving, n = 30)	*P* Value	ICC (95% CI)
SSD of posterior translation, mm[b,c]	4.4 ± 3.0	4.1 ± 3.4	.602	0.897 (0.821-0.940)
<3 mm[d]	8 (34.8)	15 (50)		
3-5 mm[d]	8 (34.8)	7 (23.3)		
>5 mm[d]	7 (30.4)	8 (26.7)		
SSD of varus gap, mm[b,c]	1.1 ± 0.9	1.2 ± 1.1	.864	0.827 (0.701-0.900)
SSD of Dial test at 30° of knee flexion, deg[b]	4.6 ± 3.3	4.8 ± 3.5	.805	0.612 (0.328-0.776)
SSD of Dial test at 90° of knee flexion, deg[b]	4.2 ± 3.4	4.9 ± 3.4	.269	0.632 (0.363-0.788)
SSD of range of motion, deg[b]	4.1 ± 5.4	4.4 ± 4.9	.637	0.861 (0.758-0.919)
Lysholm knee score[b]	82.6 ± 11.0	84.1 ± 10.7	.594	—
Follow-up Tegner activity scale[e]	3.5 (2-6)	4.3 (2-7)	.007	—
Return to activity[d]	5 (21.7)	8 (26.7)	.679	—
Near–return to activity[d]	10 (43.5)	22 (73.3)	.028	—
IKDC subjective score[b]	64.5 ± 8.8	70.6 ± 7.9	.012	—
Symptom[b]	29.0 ± 3.2	29.5 ± 3.1	.591	—
Sports[b]	22.4 ± 4.7	26.1 ± 4.1	<.0001	—
Function[b]	5.5 ± 1.4	5.7 ± 2.0	.854	—
IKDC objective grade[d]				
A	7 (30.4)	7 (23.3)	.710	—
B	10 (43.5)	18 (60.0)		
C	5 (21.7)	4 (13.3)		
D	1 (4.3)	1 (3.3)		

[a]SSD, side-to-side difference; IKDC, International Knee Documentation Committee; ICC, intraclass correlation coefficient; CI, confidence interval.
[b]The values are given as mean (standard deviation).
[c]As measured on stress radiographs made with use of the Telos device.
[d]The values are given as n (%).
[e]The values are given as mean (range).

2.6° ± 6.2° in group R; *P* = .720, ICC = 0.845) (Table 2). At the final follow-up, although both groups did show evidence of a slightly increased deficit in ROM, the difference between groups was not significant (4.1° ± 5.4° for group C and 4.4° ± 4.9° for group R; *P* = .637, ICC = 0.861) (Table 3).

Functional Knee Assessment Using Scoring Scales

Preoperatively, no significant differences were observed between the 2 groups for any of the following variables: the Lysholm knee score (58.7 ± 11.0 points for group C and 60.4 ± 8.9 points for group R; *P* = .523), preinjury Tegner activity scale (5.0 ± 1.2 for group C and 5.3 ± 1.2 for group R; *P* = .241), preoperative Tegner activity scale (2.2 ± 0.7 for group C and 2.4 ± 0.8 for group R; *P* = .273), IKDC subjective score (40.9 ± 8.7 for group C and 41.6 ± 10.5 for group R), or IKDC objective grade (*P* = .799) (Table 2).

At the final follow-up visit, the mean Lysholm knee score was 82.6 ± 11.0 points for group C and 84.1 ± 10.7 for group R, which did not differ significantly (*P* = .594). The grade frequencies on the IKDC examination form also did not differ significantly between groups (*P* = .710). However, the mean follow-up Tegner activity scale (3.5 ± 0.8 for group C and 4.3 ± 1.1 for group R; *P* = .007) and IKDC subjective score (64.5 ± 8.8 points for group C and 70.6 ± 7.9 points for group R; *P* = .012) were both significantly higher in the patients in group R compared with those in group C. The subscale analysis of the IKDC subjective score further revealed that the subscore related to sports activities was statistically higher in group R than in group C (26.1 ± 4.1 points vs 22.4 ± 4.7 points; *P* < .0001). Although the percentage of patients who reached return to activity did not differ significantly between groups (21.7% for group C and 26.7% for group R; *P* = .679), the percentage achieving near–return to activity was significantly higher in group R (73.3%) than in group C (43.5%) (*P* = .028) (Table 3).

Multivariate Analysis

Because remnant preservation did seem to relate to the follow-up Tegner activity scale, near–return to activity percentage, or IKDC subjective score, multiple linear regression analyses and logistic regression analyses were employed to adjust for compounding factors. These measures revealed that the preinjury Tegner activity scale and the use of surgical methods incorporating remnant preservation both significantly affected the follow-up Tegner activity scale (*P* < .0001 and *P* = .032), the IKDC subjective score (*P* = .061 and *P* = .047), and near–return to activity percentage (*P* = .003, odds ratio = 5.744; and

P = .005, odds ratio = 14.641) (see the Appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/).

DISCUSSION

To date, most studies have suggested that isolated PCL injuries can be treated nonoperatively, resulting in favorable short-term outcomes.[33] However, surgical intervention has typically been indicated when PCL injuries present with significant laxity or with other comorbid ligament injuries to the ipsilateral knee. Various techniques and graft selections for PCL reconstruction have been proposed to improve functional outcomes and restore normal kinematics. Over the past few years, some evidence has emerged suggesting that the preservation of any remnants of the ruptured cruciate ligament not only will improve the postoperative stability of the reconstructed ligament but will also increase the recovery of proprioception.[3,25,26,39,43]

Specifically, interest in the proprioception mediated by mechanoreceptors within the cruciate ligaments has greatly increased. In general, ligaments around joints contain mechanoreceptors that are involved in providing the central nervous system with information about joint position and movement.[23,35,38] A loss of this proprioception may inhibit protective reflexes in the affected joint, ultimately contributing to degenerative changes.[10,11] Unfortunately, in comparison with the ACL, PCL receptors and proprioception remain remarkably underresearched. In one of the few studies focusing exclusively on the PCL, Franchi et al[12] demonstrated using histologic analysis that the PCL possesses a network of neurons and mechanoreceptors that occupies 1% of the total area of the ligament. That the PCL has better synovial coverage, blood circulation, and healing potential than does the ACL[36,37] may explain the success of nonsurgical treatments for isolated PCL injuries.[39] Arthroscopic examinations of PCL-insufficient knees usually demonstrate well-maintained continuity of the PCL even though it might be attenuated.[2,9,25] However, in most conventional PCL reconstructions, any remaining PCL fibers are removed for easier tunnel positioning and graft passage.

Girgis et al[14] reported that the PCL is narrowest at midsubstance, averaging 11 mm, and fans out superiorly and to a lesser extent inferiorly. The midsubstance of the ligament is approximately one third the diameter of both the femoral and tibial insertion sites.[19] A recent anatomic study by Lopes et al[29] demonstrated that the average area of the femoral footprint of the PCL was 209 mm^2. In another anatomic study, Tajima et al[40] reported that the area of the tibial footprint of the PCL averaged 243 mm^2. Because of this morphologic character of the PCL, single-bundle reconstruction may not cover the entire footprint of the PCL. Although several PCL reconstruction techniques that incorporate remnant preservation have been presented,[1,2,25,39] our remnant-preserving technique represents an entirely novel approach. In the cases described here, the tibial tunnel was positioned underneath the tibial remnant, which was temporarily removed intraoperatively. In PCL-tibial attachments, the anterolateral fibers are on the anterior aspect, while the posteromedial fibers remain posterior. Therefore, during anterolateral single-bundle PCL reconstructions, grafts should be advanced from the tibia underneath the PCL remnant to minimize graft kinking.[4] This technique may also preserve blood supply to the PCL remnant via any posterior periligamentous vessels in the surrounding posterior soft tissue,[34] ultimately serving to promote vascular ingrowth and graft incorporation. On the femoral side, a femoral socket landmark was prepared using a blade and osteotome and was subsequently reamed in the counterclockwise direction to preserve as much of the remnant as possible.

Several studies regarding PCL reconstruction techniques that incorporate remnant preservation have reported favorable outcomes.[3,24,25] In their study of 61 patients who underwent transtibial PCL reconstructions that preserved PCL fibers, Ahn et al[3] showed an improvement in the mean Lysholm knee score from 65.8 to 92.9 at an average follow-up of 40.8 months and reported "normal" or "nearly normal" ratings on IKDC objective evaluations among 59 patients (97%). In this study, the mean SSD determined by KT-2000 arthrometer was reported as 2.79 mm. Another study from Jung et al[25] that analyzed the clinical outcomes of 49 patients who underwent tensioning of the remnant PCL and reconstruction of the anterolateral PCL bundle using a modified inlay technique found significant improvements in SSD of posterior translation according to a posterior stress radiograph and KT-1000 arthrometer (2.2 $\pm$ 1.1 mm and 1.9 $\pm$ 1.0 mm, respectively), functional score (quantified as a mean Orthopadishe Arbeitsgruppe Knie score of 91 $\pm$ 7.3), and final IKDC score (normal or nearly normal, 87.7%) at a mean follow-up of 45.7 months (range, 24-78 months). However, all of these studies were case series. In the current study, after comparing the conventional PCL reconstruction group (where remnant preservation was not performed) with the group in which remnant preservation was incorporated in PCL reconstruction, no significant differences in ligament stability, including posterior laxity and IKDC objective grade, were observed at the final follow-up. Although it seems possible that retention of the slack remnant fiber may increase mechanical stability during graft incorporation, this has not yet been demonstrated. In addition, the effects of laxity on functional outcomes of both operative and nonoperative techniques remain uncertain: while several studies have reported no correlation between laxity and functionality, other data suggest that the level of instability is predictive of loss of function.[16]

One particularly interesting result reported here is the higher mean Tegner activity level and IKDC subjective score of the remnant-preservation group at the final follow-up visit compared with that of the conventional group, although the difference of these subjective outcomes might be regarded as clinically insignificant.[21] The IKDC has been well-established in patients with various knee disorders, including meniscal disorders, ACL injuries, and patellar instability.[5,20] However, depending on the population of interest, the Tegner activity level may not accurately represent the quality of daily living and instead

is widely used to complement other outcome instruments. Although one recent study from Briggs et al[7] did validate that the Tegner activity scale adequately reflected difficulty with both activities of daily living and sports activities, comparisons of mean activity levels between the 2 groups may not allow for determination of clear change in individual activity level. Accordingly, the percentage of patients who achieved their respective preinjury activity levels was quantified and was found to not differ significantly according to group, with only 21.7% and 26.7% of patients fully regaining their preinjury activity levels in the conventional and remnant-preserving groups, respectively. This result may have been affected by the narrow inclusion criteria of this study, which selected for inclusion patients with combined PCL and PLRI injuries. Hammoud et al[18] conducted a systematic review for outcomes of PCL reconstruction and indicated that in the combined PCL studies, return to preinjury activity level ranged from 19% to 68%, while in the isolated PCL studies, 50% to 82% of patients were able to return to preinjury activity level. Meanwhile, significantly more patients in the group with remnant preservation nearly resumed their preinjury activity level, which might imply that preservation of the PCL remnant during reconstruction correlates with regained proprioceptive control in the reconstructed knee.

Although only single-bundle transtibial PCL reconstruction with anatomic posterolateral corner reconstruction was included to reduce the heterogeneity of the study population, possible confounding factors could have nonetheless affected the results. Multivariate analyses after adjusting for confounding effects indicated that both preinjury Tegner activity level and surgical method (remnant preservation or not) independently affected follow-up activity-related results: the Tegner activity scale, the IKDC subjective scale, and near–return to activity percentage. Preinjury activity levels of patients are recognized as important prognostic factors in ligament surgery, as active patients have different expectations and demands compared with those of patients who are relatively sedentary.[30] Accordingly, our data demonstrate that incorporation of remnant preservation in PCL reconstruction is a significant, independent variable for activity-related clinical outcomes.

The limitations of the present study should be noted. First, the study was retrospective in nature, which is associated with the risk of measurement bias. We took steps to mitigate this risk; radiologic measurements and manual examinations were performed by 2 different observers, and reliability studies were done. Although posterolateral rotatory instability was not a major issue of the current study, the measurement of this variable using the Dial test is subjective and not consistent with the relatively low intraclass correlation coefficient. Second, to assess the proprioceptive function,[17] no objective test such as joint kinesthesia or joint position sense was done, which may not be in accordance with results of activity-related scores in this study. Third, our study was limited by the narrow inclusion criteria for surgical techniques to increase homogeneity in the study populations; therefore, these results cannot be directly applied to patients treated with other surgical techniques. Fourth, given the total number of cases included and the mean and standard deviation values of variables, the present study had insufficient statistical power to accept the null hypothesis.

In conclusion, techniques combining remnant-preserving transtibial single-bundle PCL reconstruction with posterolateral corner reconstruction do not appear to provide increased posterior stability compared to that of conventional transtibial single-bundle PCL reconstruction approaches combined with posterolateral corner reconstruction. Although the incorporation of remnant preservation did result in somewhat better activity-related clinical outcomes versus those of techniques without remnant preservation, to clearly define the clinical effect of remnant preservation in PCL reconstruction, well-designed prospective studies with larger sample sizes and longer follow-up periods should be performed.

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