Return to Sports and Clinical Outcomes After Arthroscopic Anatomic Posterior Cruciate Ligament Reconstruction With Remnant Preservation

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Purpose: To evaluate the clinical outcomes of transtibial posterior cruciate ligament reconstruction (PCLR) with remnant preservation in highly active patients and to investigate the rate of return to sports (RTS), quality of sports activities, and patient satisfaction. **Methods:** Patients with a Tegner activity scale of >5 who underwent isolated PCLR from 2013 to 2016 with minimum 2-year follow-up were retrospectively reviewed. Single-bundle PCLR was performed using fresh frozen allograft irradiated with 50 kGy. Subjective assessments included the Lysholm score, subjective International Knee Documentation Committee score, and Tegner activity scale. A questionnaire elicited information associated with RTS and satisfaction. Functional tests included isokinetic muscle strength and single-leg hop tests. **Results:** We evaluated 52 patients, with a mean (± standard deviation) follow-up duration of 29.5 ± 8.6 months. The subjective assessments and functional tests significantly improved postoperatively (all $P < .001$). Mean time to return to full sports activity was 9.7 ± 5.1 months. Thirty-eight (73.1%) and 45 (86.5%) patients could return to previous sports activities at 9 and 24 months, respectively. A sports-experience questionnaire indicated that 48% and 69.2% of the patients were participating with unlimited effort and performance, respectively, and no pain at 9 and 24 months. Multivariate analysis indicated that extensor deficit (odds ratio [OR] 4.2, 95% confidence interval [CI] 1.342 to 17.839), flexor deficit at 60°/s (OR 3.8, 95% CI 1.081 to 14.476), Limb Symmetry Index (%) for the single-leg vertical jump test (OR 2.2, 95% CI 1.212 to 9.227), and satisfaction (OR 2.8, 95% CI 1.186 to 10.281) were significantly associated with failure of not returning to preinjury sports activity levels at the 9-month follow-up. **Conclusions:** Arthroscopic anatomic PCLR with remnant preservation showed high rates of RTS and high patient satisfaction, as well as satisfactory clinical results in highly active patients. This surgical technique could be an effective treatment for grade III posterior cruciate ligament injury in highly active patients. **Level of Evidence:** Level IV, therapeutic case series.

Recent studies have reported that the outcomes of arthroscopic transtibial single-bundle posterior cruciate ligament reconstruction (PCLR) are not significantly different from the tibial inlay technique.[1-3] Arthroscopic transtibial single-bundle PCLR presents some advantages over the tibial inlay technique or double-bundle PCLR, because it is a relatively simple procedure with a short operation time and low morbidity.[4-6] Success or clinical efficacy of any ligament reconstruction is often defined, rightly or wrongly, by the ability of return to sports (RTS), and function after isolated PCLR is receiving increasing interest.[7-9]

In this context, early restoration of stability and function and complete RTS after the PCLR, a safe and minimally invasive procedure, would be meaningful for the high-demand patient population desiring to return to sports activities, in terms of both level of participation and time required.[10-12] Various PCLR techniques to improve graft healing and maturation have been associated with clinical outcomes, especially regarding stability and function.[13-16] Preservation of the remnant posterior cruciate ligament (PCL) fibers, including Humphrey and Wrisberg ligaments, during PCLR can be considered to promote graft healing and support

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graft properties.[4,17-21] Several studies have indicated that remnant preservation techniques enhanced revascularization and regeneration of mechanoreceptors and showed a lower signal intensity in the late stage on follow-up magnetic resonance imaging (MRI).[22,23] Ahn et al.[17] reported that objective evaluation of outcome was normal or nearly normal in 97% of patients, and poor results resulting from the "killer turn" effect could be reduced by preserving the remnant PCL fibers after transtibial PCLR. Lee et al.[18] also revealed that transtibial PCLR with remnant fiber preservation resulted in successful clinical, functional, and morphological outcomes. They suggested that anatomic single-bundle PCLR with remnant preservation could lead to less graft loosening induced by the killer turn effect and restore sensations for joint motion. In their study, knee function improved and proprioception was similar to that of the uninjured knee after PCLR with remnant preservation.

However, there has been limited research focusing on the RTS after PCLR in high-demand patients. Previous studies had relatively few subjects, lacked comprehensive analysis, or did not evaluate tibial tunnel position or graft maturation after transtibial PCLR.[24,25]

The purpose of this study was to evaluate clinical outcomes of transtibial PCLR with remnant preservation in highly active patients before injury and to investigate the rate of RTS, the quality of sports activities, and patient satisfaction after PCLR. We hypothesized that the remnant PCL fiber preservation technique would result in good clinical outcomes and lead to a high rate of RTS and high patient satisfaction. Furthermore, we hypothesized that the quality of RTS activity and patient satisfaction would be positively correlated.

Methods

Patient Selection

The patients who underwent isolated PCLR reconstruction at our institute from March 2013 to April 2016 were retrospectively reviewed. Indication for PCLR was grade III (>10 mm) PCL injury. Patients were included if they underwent primary PCLR with remnant preservation using posterior trans-septal portal, with 3-dimensional computed tomography (3D CT) and MRI examination postoperatively, were available for follow-up evaluation for ≥24 months, and presented a Tegner activity scale of >5 before injury (highly active patients). Exclusion criteria were combined posterolateral injuries higher than grade II (a difference of 10° between the 2 sides on the dial test at 30° and 90° with >5-mm increase in the lateral joint gap compared with the uninvolved knee on varus stress radiography), multiple ligament injuries, bilateral injuries, subtotal meniscectomy or total meniscectomy at index surgery, combined fractures, prior surgery on the involved knee, malalignment, and infection. Fourteen patients were excluded due to combined posterolateral complex injury higher than grade II. This retrospective study was performed with the approval of the ethics committee of Konkuk University Medical Center (KUH1060169).

Surgical Technique

A dial test under anesthesia (spinal or general), with the patient supine, was performed to evaluate combined posterolateral instability.[26] Medial rotatory instability was evaluated by checking the anterior subluxation of the medial tibial plateau on the medial femoral condyle during the valgus stress with the knee in 30° of flexion. When concomitant ligament injuries are higher than grade II, we conduct combined posterolateral ligament reconstruction or medial complex reconstruction.[27]

Isolated PCLR with remnant fiber preservation using a trans-septal portal was performed by a single experienced surgeon (J.G.K.). A fresh-frozen allograft (usually tibialis anterior or posterior), irradiated with 50 kGy and controlled by tissue preservation technique (Clearant Process; Korea Bone Bank, Seoul, Korea), was used. Without damaging the remnant PCL fibers or iatrogenic neurovascular injury, the tibial tunnel was prepared.[6] The guide tip was advanced to ∼15 to 20 mm below the joint line and slightly lateral (2 to 3 mm) of the original PCL tibial attachment site at 90° flexion.[28] Accumulated experience allowed a anatomic tibial tunnel, between 8 and 9 mm in diameter, to be created under direct visualization via the posteromedial portal without the need for intraoperative radiographs.[6] After tibial tunnel preparation, a guide pin was inserted into the anterolateral femoral footprint via a new accessory anterolateral portal. Next, the femoral tunnel, which was 30 mm deep and 8 to 9 mm in diameter and matched to the graft size, was created. The graft was pulled into the femoral tunnel using the inside-out and press-fit methods, fixed with 2 cross pins (RigidFix System; DePuy Mitek, Raynham, MA), and pulled out through the tibial tunnel. The graft was fixed to the tibial tunnel with 2 bioabsorbable interference screws (Smith & Nephew, London, UK) at 90° flexion. We usually use a 25-mm screw (8 to 9 mm in diameter) for proximal fixation (proximal entrance) and a 20-mm screw (8 to 9 mm in diameter) for distal fixation (distal exit) (Appendix Figure 1, panel E).

Postoperative Rehabilitation

The hinged knee brace (Legend; Donjoy, Vista, CA) was applied for 8 weeks after PCLR, locked in full extension for the first 3 weeks. Partial weightbearing was started immediately, and full weightbearing was delayed for 4 weeks. Prone passive flexion exercise was

started 3 weeks after surgery, with 90° range of motion allowed at 4 weeks and 120° range of motion at 6 weeks. Progressive closed kinetic chain training was started within 4 weeks, followed by open kinetic chain exercises. Costrengthening exercises, comprising mini-squatting and calf raising, were recommended during the early phases, because these cause cocontraction of the hamstring and quadriceps muscles. Sports-specific training was allowed 6 months after the surgery based on muscle recovery and knee function assessment. Competitive sports were delayed to 9 months.

CT Evaluation

A 64-detector row 3D CT scan (LightSpeed VCT XT; GE Medical Systems, Milwaukee, WI) was performed within 1 week after the PCLR. All patients who underwent PCLR were advised to undergo 3D CT scan and provided informed consent for the CT evaluation to assess tibial tunnel position and breakage of the tunnel, which is helpful for postoperative management. A 3D reconstructed surface model was made based on the viewed image to properly display the entire area of the PCL fovea on the tibial plateau.[28] In addition, the PCL fovea parallel to the plane was used to evaluate the tibial tunnel position. The tibial tunnel position was evaluated using 5 parameters: (1) total sagittal length of the PCL fovea (sagittal distance from the posterior border of the tibial spine to the posterior margin of the PCL fovea), (2) sagittal distance from the center of the tibial tunnel to the posterior margin of the PCL fovea (sagittal tunnel position), (3) total coronal length of PCL fovea (coronal dimension of the PCL fovea from the medial margin to the lateral margin), (4) coronal distance from the medial margin of the PCL fovea to the center of the tibial tunnel (coronal tunnel position), and (5) length of the posterior bone bridge (the nearest distance from the posterior border of the tibial tunnel to the posterior cortex) (Appendix Figure 1).[28] The sagittal tibial tunnel position was measured using the ratio between no. 1 and no. 2, and the coronal tibial tunnel position was measured using the ratio between no. 3 and no. 4. A negative value for no. 5 indicated posterior cortex breakage. All measurements were performed in duplicate by 2 orthopaedic surgeons (J.G.K. and D.W.L.), and mean values were calculated for analyses with a picture archiving and communication system workstation (Centricity RA 1000; GE Healthcare).

MRI Evaluation

MRIs were obtained ≥12 months after PCLR. Follow-up MRI for the evaluation of the reconstructed PCL graft was recommended for all patients, for which informed consent was provided. All patients strongly desired to confirm the status of the reconstructed PCL graft. Patients underwent MRI using a 3.0-T system (Signa HD; GE Healthcare) with the following sequences of the knee of interest: (1) axial proton density fat saturated: repetition time, 2,000; echo time, 35; echo train length, 8; bandwidth, 42; field of view, 16 cm; 384 × 384; and 3-mm contiguous; (2) coronal proton density fat saturated: repetition time, 2,000; echo time, 35; echo train length, 8; bandwidth, 42; field of view, 16 cm; 384 × 384; and 2-mm contiguous; and (3) sagittal proton density fat saturated: repetition time, 2,000; echo time, 35; echo train length, 8; bandwidth, 42; field of view, 16 cm; 384 × 384; and 2-mm contiguous. Gross appearance and signal intensity of the PCL graft were evaluated using a modified grading system proposed in previous studies.[17,18] The gross appearance was graded as grade I (normal), grade II (continuous but deformed or thin), or grade III (discontinuous in the sagittal and coronal planes). The signal intensity of the PCL graft using a 4-level classification system by Howell et al.[29] was assessed independently in the proximal, middle, and distal zones. The PCL graft signal intensity was rated from 0 to 3 for each zone of the graft: a homogeneous low-signal intensity within the entire graft was rated 0, ≥50% of the normal-appearing signal was rated 1, <50% of a normal-appearing signal was rated 2, and a diffuse increase in signal intensity with an abnormal appearance was rated 3.[18,29] Therefore, the total signal intensity scores ranged from 0 to 9 (3 points for each of the 3 zones). All measurements were performed in duplicate by 2 orthopaedic surgeons (J.G.K. and D.W.L.), and mean values were used.

Stress Radiography Evaluation

Posterior stress radiographs were obtained on the day before surgery, 12 months after surgery, and every year thereafter. Posterior laxity was assessed by posterior force (150 N) with the Telos stress device (Austin Associates, Baltimore, MD) at 90° of knee flexion in neutral rotation. Posterior stress tests were conducted for both the uninvolved and involved knees, and side-to-side differences (STSD) were calculated.

Clinical Assessment

Subjective assessments and objective tests were performed before surgery and 9, 12, and 24 months postoperatively. For subjective knee function assessments, the Lysholm score, International Knee Documentation Committee (IKDC) subjective knee score, and Tegner activity scale were evaluated. A questionnaire was provided to elicit information associated with RTS with activity level, time taken to RTS, reasons for not returning to sport, and patient satisfaction proposed by previous studies.[7,30] The quality of the RTS was also assessed with a sports-experience question (unlimited effort, unlimited performance, and no pain; unlimited

Table 1. Demographic and Clinical Characteristics (N = 52)

Age (yr)	25.8 ± 5.0
Sex (male/female)	47/5
Body mass index (kg/m^2)	23.8 ± 2.5
Time from injury to operation (mo)	2.4 ± 1.9
Clinical follow-up duration (mo)	29.5 ± 8.6
MRI follow-up duration (mo)	15.8 ± 5.4
Pre-Lysholm score	54.9 ± 11.2
Pre-IKDC subjective score	51.8 ± 10.7
Preinjury Tegner activity scale	7.9 ± 1.4
Preoperative Tegner activity scale	4.3 ± 1.5
Meniscus surgery	
None	31
Meniscal repair	6
Partial meniscectomy	15
Sports, n (professional players)	
Soccer	35 (10)
Baseball	6 (2)
Basketball	1
Taekwondo	3 (3)
Judo	2 (1)
Other	5

NOTE. Data are mean ± standard deviation unless noted otherwise. IKDC, International Knee Documentation Committee; MRI, magnetic resonance imaging.

effort, unlimited performance, and some pain; unlimited effort and limited performance; limited effort and limited performance; and disabled).[7] Responses regarding patient satisfaction were elicited using a 5-point ordinal satisfaction scale (very satisfied = 5, somewhat satisfied = 4, neither satisfied nor dissatisfied = 3, somewhat dissatisfied = 2, and very dissatisfied = 1). This question has been used in previous studies to investigate patient satisfaction after anterior cruciate ligament reconstruction.[7]

Objective assessments included the isokinetic extensor muscle strength test and functional performance tests. Isokinetic extensor and flexor muscle strength tests at an angular velocity of 60°/s (Nm/kg) using a Biodex System III dynamometer (Biodex Medical Systems, Shirley, NY) were conducted. The strength test was taken first on the uninvolved side, followed by the involved side, and the deficit (%) was calculated as follows: [(peak muscle torque of the uninvolved side − peak muscle torque of the involved side)/peak muscle torque of the uninvolved side] × 100. Functional performance tests included a single-leg hop for distance test as presented by Noyes et al.[31] and a single-leg vertical jump (SLVJ) test as described by Hopper et al.[32] The functional tests were taken first on the uninvolved side, followed by the involved side, and the Limb Symmetry Index (LSI, %) was calculated by dividing the data of involved side by the uninvolved side and multiplying the result by 100.[33,34] All tests were evaluated by one of the authors (S.I.C.), who was blinded to the procedures.

Statistical Analysis

Statistical analysis was performed using SPSS software (IBM SPSS Statistics 21; IBM Corp, Somers, NY). The independent *t* test or Mann−Whitney *U* test was used to compare parametric or nonparametric variables. Preoperative and postoperative parametric or nonparametric variables were compared by the paired *t* test or Wilcoxon's signed-rank test. To compare categorical variables, we used the chi-squared test or Fisher's exact test. The Spearman correlation coefficient was used to analyze the relation between RTS and satisfaction. The results of the regression analysis were presented as odds ratios (ORs) and 95% confidence intervals (CIs). For all tests, a P value $< .05$ was considered statistically significant.

Results

Fifty-two of 74 patients meeting the inclusion criteria were evaluated, of whom 16 were professional athletes. The mean clinical follow-up duration was 29.5 ± 8.6 months. The demographic and clinical characteristics of the patients are shown in Table 1.

CT Evaluation

The results of tibial tunnel evaluation are presented in the Appendix Table 1.

MRI Evaluation

Of 52 patients, 78.8% showed normal graft appearance, and none showed graft discontinuity in the sagittal or coronal planes. Forty (76.9%), 42 (80.8%), and 45 (86.5%) patients presented low signal intensity at the proximal, middle, and distal zones, respectively. The killer-turn effect was not observed in any patient, and the mean score of the signal intensity at the distal zone was below that at the proximal zone (Table 2).

Table 2. Magnetic Resonance Imaging Results of Graft Appearance and Graft Signal Intensity (N = 52)

Graft gross appearance	
Grade I (normal)	41 (78.8)
Grade II (continuous but deformed or thin)	11 (21.2)
Grade III (discontinuous)	0
Graft signal intensity score	
Proximal zone, mean score	0.9 ± 0.9
0 to 1	40 (76.9)
2 to 3	12 (23.1)
Middle zone, mean score	0.8 ± 0.7
0 to 1	42 (80.8)
2 to 3	10 (19.2)
Distal zone, mean score	0.7 ± 0.7
0 to 1	45 (86.5)
2 to 3	7 (13.5)

NOTE. Data are n (%) or mean ± standard deviation.

Table 3. Comparison of Preoperative and Postoperative Outcomes (N = 52)

Outcome	Preoperative	Follow-up			
		9 mo	*P*	Last	*P*
Lysholm score	54.9 ± 11.2	85.7 ± 15.8	<.001	89.4 ± 12.3	.186
Subjective IKDC score	51.8 ± 10.7	86.1 ± 18.4	<.001	88.7 ± 14.1	.421
Extensor strength, deficit (%)	28.6 ± 12.5	14.4 ± 8.2	<.001	12.7 ± 10.5	.360
Flexor strength, deficit (%)	30.4 ± 15.6	12.3 ± 10.2	<.001	10.1 ± 9.6	.261
LSI for SLHD test, %	77.2 ± 14.7	90.2 ± 11.4	<.001	93.9 ± 13.2	.129
LSI for SLVJ test, %	68.7 ± 19.1	90.7 ± 10.2	<.001	94.1 ± 13.8	.156

NOTE. Data are mean ± standard deviation.

IKDC, International Knee Documentation Committee; LSI, limb symmetry index; SLHD, single leg hop for distance; SLVJ, single leg vertical jump.

Stress Radiography Evaluation

The STSD on posterior stress radiography using the Telos device improved significantly. The mean STSD decreased from 12.6 ± 2.7 mm preoperatively to 2.9 ± 1.4 mm at last follow-up ($P < .001$).

Clinical Assessment

The Lysholm score improved from 54.9 ± 11.2 preoperatively to 85.7 ± 15.8 at 9 months and 89.4 ± 12.3 at last follow-up, and the IKDC subjective score varied from 51.8 ± 10.7 to 86.1 ± 18.4 at 9 months and to 88.7 ± 14.1 at last follow-up (Table 3). Extensor peak torque at angular velocity of 60°/s and deficit improved from 135.2 ± 35.9 to 231 ± 39.1 Nm/kg at 9 months and 239 ± 42.3 Nm/kg at last follow-up and from 28.6% ± 12.5% to 14.4% ± 8.2% at 9 months and 12.7% ± 10.5% at last follow-up, respectively (Table 3). Flexor peak torque at an angular velocity of 60°/s and deficit improved from 74.2 ± 32.9 to 123 ± 38.1 Nm/kg at 9 months and 127 ± 33.8 Nm/kg at last follow-up and from 30.4% ± 15.6% to 12.3% ± 10.2% at 9 months and 10.1% ± 9.6% at last follow-up, respectively (Table 3). The LSI for single-leg hop for distance test improved from 77.2% ± 14.7% preoperatively to 90.2% ± 11.4% at 9 months and 93.9% ± 13.2% at last follow-up, and the SLVJ test, from 68.7% ± 19.1% to 90.7% ± 10.2% at 9 months and 94.1% ± 13.8% at last follow-up (Table 3).

RTS and Satisfaction

The mean times to return to any sports activity and full sports activity were 6.2 ± 3.8 and 9.7 ± 5.1 months, respectively. All patients (100%) were able to return to any sports activity at 9 and 24 months after PCLR. Thirty-eight (73.1%) patients (of 52) were able to return to previous sports activities at 9 months after PCLR and 45 (86.5%) maintained their previous sports activity level at 24 months after surgery. The average preinjury and preoperative Tegner activity scale scores were 7.9 ± 1.4 and 4.3 ± 1.5, respectively ($P < .001$).

Table 4. Return to Sports and Patients Satisfaction at 9- and 24-Mo Follow-up (N = 52)

Measure	9 mo	24 mo	*P*
Tegner activity scale	7.4 ± 1.6	7.8 ± 1.4	.004
Rate of return to any sport activity	52 (100)	52 (100)	.000
Rate of return to preinjury level of sport activity	38 (73.1)	45 (86.5)	.035
Sports experience			<.001
Unlimited effort, unlimited performance, no pain	25 (48)	36 (69.2)	
Unlimited effort, unlimited performance, some pain	14 (26.9)	9 (17.3)	
Unlimited effort, limited performance	8 (15.4)	4 (7.7)	
Limited effort, limited performance	4 (7.7)	2 (3.8)	
Disabled	1 (1.9)	1 (1.9)	
Reason for not returning to sport			.157
Unclear	2 (14.3)	0	
Apprehension	6 (42.9)	4 (57.1)	
Physical limitation	5 (35.7)	1 (14.3)	
Not related to knee function	1 (7.1)	2 (28.6)	
Satisfaction scale, mean points	4.4 ± 1.1	4.6 ± 0.9	.001
Very satisfied	34 (65.4)	42 (82.7)	
Somewhat satisfied	9 (17.3)	5 (9.6)	
Neither satisfied nor dissatisfied	4 (7.7)	2 (3.8)	
Somewhat dissatisfied	3 (5.8)	2 (3.8)	
Very dissatisfied	2 (3.8)	1 (1.9)	

NOTE. Data are mean ± standard deviation or n (%).

Table 5. Clinical Variables of Return to Preinjury Level and Nonreturn Groups at 9-Mo Follow-up

Variable	Return (n = 38)	Nonreturn (n = 14)	*P*
Age (yr)	25.2 ± 4.1	26.1 ± 3.6	.632
Sex (male/female)	36/3	11/2	.367
Body mass index (kg/m^2)	24.1 ± 3.9	23.9 ± 3.3	.528
Lysholm score	87.7 ± 20.1	83.7 ± 17.3	.575
IKDC score	86.9 ± 18.3	81.1 ± 20.4	.581
Tegner activity scale	7.9 ± 1.5	6.0 ± 1.0	<.001
STSD on posterior stress radiography (mm)	3.0 ± 0.9	2.8 ± 1.2	.170
Graft signal intensity score on MRI			
Proximal zone	0.8 ± 0.6	0.9 ± 0.7	.449
Middle zone	0.7 ± 0.8	0.7 ± 0.9	.553
Distal zone	0.6 ± 0.7	0.7 ± 0.8	.506
Extensor deficit at 60°/s	9.5 ± 5.8	20.8 ± 10.3	<.001
Flexor deficit at 60°/s	11.6 ± 6.8	21.2 ± 11.8	.001
LSI for SLHD test (%)	95.8 ± 11.8	88.6 ± 10.5	.050
LSI for SLVJ test (%)	94.7 ± 10.1	87.2 ± 9.7	.022
Satisfaction scale	4.8 ± 0.6	3.2 ± 1.3	<.001

NOTE. Data are mean ± standard deviation unless noted otherwise.

IKDC, International Knee Documentation Committee; MRI, magnetic resonance imaging; LSI, limb symmetry index; SLHD, single leg hop for distance; SLVJ, single leg vertical jump; STSD, side-to-side difference.

At 9 and 24 months after PCLR, the average Tegner activity scale scores were 7.4 ± 1.6 and 7.8 ± 1.4, respectively ($P = .004$) (Table 4).

The sports-experience question regarding the quality of the RTS showed that 48% and 69.2% were participating with unlimited effort, unlimited performance, and no pain at 9 and 24 months after PCLR (Table 4). At 9 and 24 months after the index surgery, 82.7% and 92.3% reported being very satisfied or somewhat satisfied with the outcome of PCLR. There were significant correlations between the sports-experience question and satisfaction at 9 and 24 months ($r = 0.582$ and 0.626, respectively; $P < .001$). Common reasons for not returning to a previous activity level were apprehension (42.9%) and physical limits (35.7%) at 9 months and apprehension (57.1%) and problems unrelated to knee function (28.6%) at 24 months (Table 4).

Analysis of Clinical Parameters for Nonreturn to Preinjury Level

Clinical parameters for patients who did not return to preinjury level of sports activity at 9-month follow-up are presented in Table 5. Based on multivariate analysis, extensor deficit at 60°/s (OR 4.2, 95% CI 1.342 to 17.839), flexor deficit at 60°/s (OR 3.8, 95% CI 1.081 to 14.476), LSI for SLVJ test (OR 2.2, 95% CI 1.212 to 9.227), and satisfaction scale (OR 2.8, 95% CI 1.186 to 10.281) were significant factors associated with failure to return to preinjury levels of sports activities at the 9-month follow-up (Table 6). There was significant association between nonreturn to preinjury level and high signal intensity at middle and distal zones, although there were no significant differences in mean score of signal intensity between return and nonreturn (Table 7).

Discussion

The main finding of the present study was that arthroscopic anatomic PCLR with remnant preservation using a posterior trans-septal portal resulted in high rates of return to preinjury levels of sports activities (73.1% and 86.5% at 9 and 24 months, respectively) in highly active patients (a Tegner activity scale of >5 before injury). In addition, of the 52 patients included in the study, 82.7% and 92.3% reported being very satisfied or somewhat satisfied with the outcome of PCLR. The clinical results significantly improved postoperatively, and follow-up MRI showed a high rate (86.5%) of graft maturation without the killer-turn effect at distal zone. These results are meaningful for highly active patients (a Tegner activity scale of >5 before injury), because graft maturation is an important factor and has a close association with biomechanical properties and clinical outcomes.[13-16,35]

The primary goal of treatment for PCL injury is to restore anatomy and normal knee biomechanics to recover stability and prevent progressive osteoarthritis. However, the optimal treatment of isolated complete PCL tears remains controversial. Although PCL has an

Table 6. Predictors Associated with Nonreturn to Preinjury Level in Multivariable Analysis

Predictors	Odds Ratio	*P*	95% CI
Extensor deficit at 60°/s	4.2	.015	1.342 to 17.839
Flexor deficit at 60°/s	3.8	.024	1.081 to 14.476
LSI for SLVJ test (%)	2.2	.032	1.212 to 9.227
Satisfaction scale	2.8	.009	1.186 to 10.281

CI, confidence interval; LSI, limb symmetry index; SLVJ, single leg vertical jump.

Table 7. Association Between Return to Sports and Graft Maturity

Factor	Return (n = 38)	Nonreturn (n = 14)	*P*
Graft signal intensity score			
Proximal zone			.712
0 to 1	30 (75)	10 (25)	
2 to 3	8 (66.7)	4 (33.3)	
Middle zone			.016*
0 to 1	34 (81)	8 (19)	
2 to 3	4 (40)	6 (60)	
Distal zone			.011*
0 to 1	36 (80)	9 (20)	
2 to 3	2 (28.6)	5 (71.4)	

NOTE. Data are n (%).
*Statistically significant (Fisher's exact test).

intrinsic ability to heal, previous studies have reported that healing of complete PCL tears treated nonoperatively usually occurs in the lax position; however, this loose healing likely leads to residual instability and functional impairment.[36-39] Ultimately, there would also be an increased risk of osteoarthritis development and poor patient satisfaction. Zayni et al.[24] questioned whether it was appropriate to subject a high-demand patient, who desires an early RTS, into a protracted period of nonoperative treatment. They suggested that in a significant group of patients such as professional athletes, an early RTS would be prevented, and the delay in the time to PCLR might have a negative effect on outcome. In the present study with 52 patients, the preinjury Tegner activity scale was 7.9 ± 1.4, and 16 (31%) professional athletes were included in the study population. The mean time interval from injury to surgery was 2.4 ± 1.9 months. We also proposed that returning to sports activity at either the same or higher level should be considered a main outcome after PCLR in determining successful outcomes for competitive athletes.

After isolated PCLR, we conducted relatively accelerated rehabilitation. A literature review by Kim et al.[40] reported that full weightbearing was delayed until 6 weeks postoperatively in 60% of 34 studies, and most studies used a brace for 6 to 8 weeks, whereas the active hamstring curl exercise was not permitted for 6 to 24 weeks postoperatively after PCLR. In our study, partial weightbearing was started immediately, and full weightbearing was allowed at 4 weeks. Isometric quadriceps-strengthening exercises were started immediately, and progressive closed kinetic chain training was started within 4 weeks, followed by open kinetic chain exercise. Moreover, active hamstring curl exercises were allowed at 8 weeks. Based on multivariate analysis in the present study, extensor deficit at 60°/s (OR 4.2, 95% CI 1.342 to 17.839), flexor deficit at 60°/s (OR 3.8, 95% CI 1.081 to 14.476), and LSI for the SLVJ test (OR 2.2, 95% CI 1.212 to 9.227) were significant predictors associated with nonreturn to preinjury levels of sports activities at the 9-month follow-up. Therefore, our approach emphasizes early quadriceps exercises, which provide the net flexor moment required for performing knee functions; it can produce cocontraction of the quadriceps and hamstring muscles with minimal posterior shear force.[40] The SLVJ test is known to provide an assessment of muscle strength, power, and the patients' willingness to accept weight on the affected side.[41,42]

Although returning to sports after PCLR has been reported in some studies, these involved different surgical techniques in heterogeneous groups of patients examined at different time intervals from injury to surgery.[43] There is limited information available in the literature regarding the time required to return to any sports activity or to full sports activity after isolated PCLR in high-demand patients. The success of any surgical treatment should be judged in function of the patient's perception of benefits gained from the medical intervention, and thus, the importance of RTS has been recognized as a measure of clinical efficacy. MacGillivray et al.[44] reported that 92% of patients (12 of 13) were satisfied with their results after arthroscopic isolated PCLR and would have the surgery again, and 54% (7 of 13) reported no episodes of postoperative instability at a mean follow-up of 5.7 years. In their study, patients were allowed to return to full activities 9 to 12 months postoperatively. The authors did not provide any specific information regarding the surgical procedures used for arthroscopic PCLR, rate of RTS, or the time to RTS. Rauck et al.[45] analyzed 15 isolated PCL reconstructions in 14 athletes at a mean follow-up of 6.3 years; RTS rate was 79%, and overall patient satisfaction was 9.2/10. However, surgical technique and graft type were heterogenous, and the sports-experience question was vague. Zayni et al.[24] showed that 81% of 29 patients could return to the same level of activity after arthroscopic isolated PCLR at a mean follow-up of 29 months. In their study, the preinjury Tegner activity scale was 7.8 ± 1.7, and time interval from injury to surgery was 28 months (range 3 weeks to 95 months). They reported that the level of activities of 21 patients at last follow-up was similar to their level of activity before injury. However, they did not provide a detailed explanation of the surgical procedures of arthroscopic PCLR, the time to RTS, graft maturation, or killer turn effects and did not conduct objective functional tests.

In contrast, Ahrend et al.[25] reported that in 87.0% of 60 patients (age 44.8 ± 12.1 years) after surgery for isolated or combined PCL injuries, at least a 24-month follow-up was necessary before returning to sports activities, albeit with a significant reduction in the frequency ($P = .0087$), duration ($P = .0003$), and amount of regularly performed sports ($P < .0001$). The authors

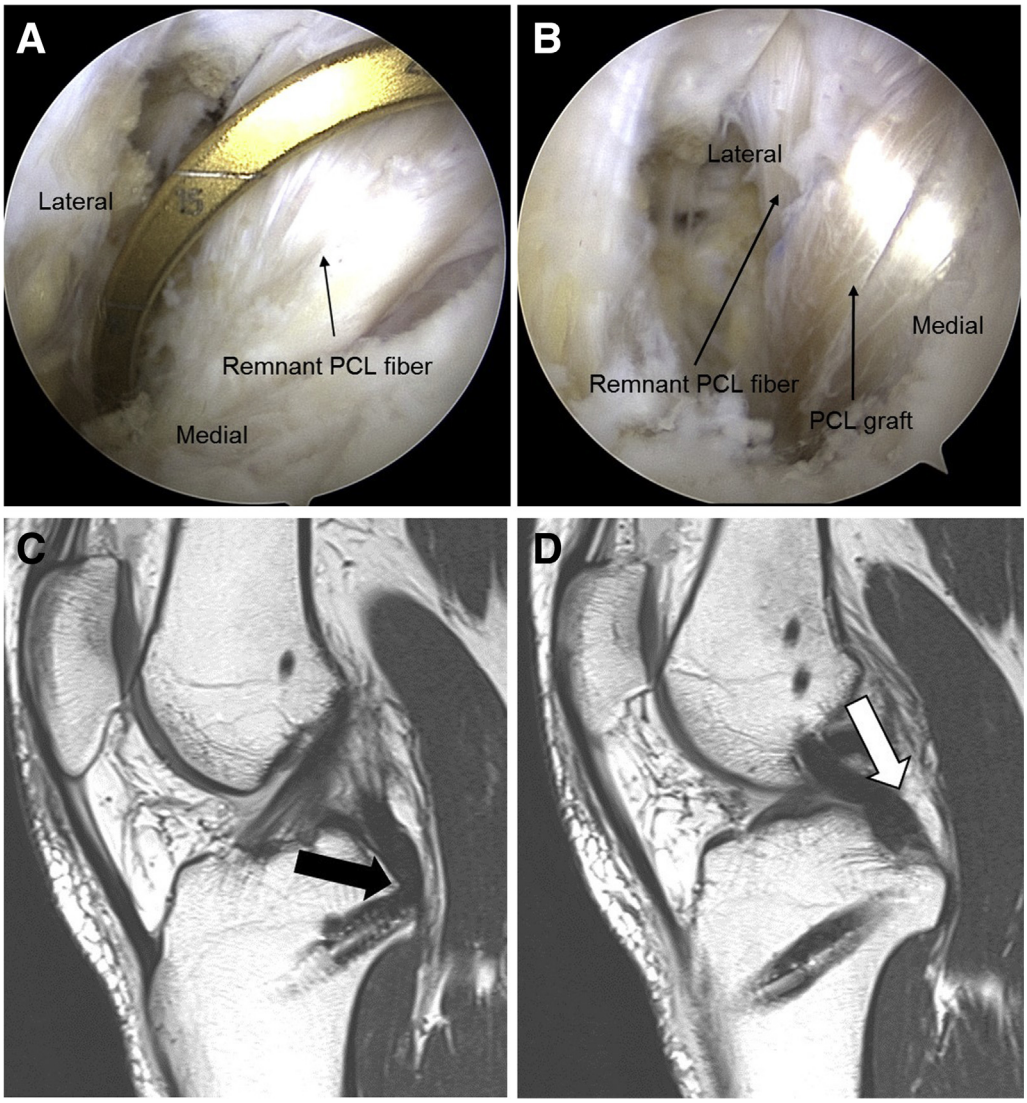

Fig 1. 23-year-old man underwent posterior cruciate ligament (PCL) reconstruction on the left knee, and magnetic resonance imaging (MRI) was obtained at 12 months after PCL reconstruction. (A) During PCL reconstruction, the guide tip was advanced to ~15 to 20 mm below the joint line with excellent visualization. (B) Remnant PCL fiber is mostly preserved. (C and D) Postoperative MRI scans of left knee at 1-year follow-up reveal complete healing without the killer-turn effect (black arrow) and PCL graft forming a broad cross-sectional area (white arrow).

concluded that for competitive athletes, a PCL injury could lead to the end of their career. However, transtibial PCLR was performed using only a posteromedial portal, and potentially a killer turn mechanism may have led to repetitive friction between graft and tunnel inlet and residual laxity. Their time to RTS was not different from that of the present study. Indeed, in our study, 69.2% of the 52 patients surveyed participated in sports activities with unlimited effort, unlimited performance, and no pain at 24 months after the surgery.

The benefit of the remnant preservation technique using a posterior trans-septal portal during arthroscopic PCLR is that the remnant tissues or the stump between the bone and the graft including the Wrisberg ligament promote graft healing by providing blood supply and revascularization, as well as protection of the remnant PCL, although the elongated remnant fibers could not contribute to increased stability.[17,18] In addition, the PCL graft is healed together with the remnant PCL fibers at the femoral and tibial attachment sites, and they form a broad cross-sectional area, similar to original double-bundle PCL (Fig 1).[6,17,18] This remnant preservation technique, which spares mechanoreceptors and prevents the killer-turn effect, can contribute to restoration of knee stability, biomechanics, and proprioception.[18,46,47] Some authors revealed that single-bundle PCL reconstruction with remnant preservation showed satisfactory outcomes regarding instability and proprioception.[21] Although definition of proprioception may vary, its importance in rehabilitating and preventing injury remains constant, because it allows the body to maintain stability and orientation during dynamic activities.[48] In our study, the interval from injury to surgery was 2.4 ± 1.9 months. We assumed that a shorter interval can have a positive role in function recovery and early RTS. A recent systematic review

identified low RTS rates (44%) in 6 studies, in which most patients undergoing PCLR had failed nonoperative treatment, as indicated by the long time from initial injury to PCLR.[43] Therefore, it is important to determine the timing of surgery and select patients who would benefit from PCLR at an early stage.

The mean score of the signal intensity at the distal zone was below that at the proximal zone in our study. The signal intensity of the graft was negatively correlated with structural properties and morphological healing, suggesting that preservation of the remnant tissue had a positive effect on graft maturation.[22,23] In the current study, there was significant association between nonreturn to preinjury level and high signal intensity at middle and distal zones. In particular, 71.4% of 7 patients who showed high signal intensity at the distal zone did not return to preinjury activity level at 9 months. The inside-out drilling technique for femoral tunnel preparation could create higher graft-femoral angles, with increased shear stress compared with outside-in drilling.[49,50] Thus, outside-in drilling for femoral tunnel can be considered to reduce the killer-turn effect. This has a potentially positive effect on graft maturation at the proximal zone.

The other benefit of this technique is that it allows the surgeon to create an accurate tibial tunnel.[4,6] We inserted the PCL tibial guide into the PCL tibial attachment site under visualization through the posteromedial portal, and the guide tip was advanced to ~15 to 20 mm below the joint line. Estimation of the PCL fovea with the tip of PCL guide is possible if the posterior trans-septal portal is created with excellent visualization. In our study, we analyzed the location of the tibial tunnel within the PCL fovea using 3D CT after PCLR. The sagittal distance from the center of the tibial tunnel to the posterior margin of the PCL fovea was 6.2 ± 2.7 mm, and the ratio between the total sagittal length of the PCL fovea and sagittal tunnel position was 32.5% ± 15.4%. Moorman et al.[51] showed that the center of the working PCL fibers was 7 mm anterior to the posterior cortex of the tibia, measured along the PCL fovea, in the sagittal plane. We suggest that a slightly posteriorly positioned tibial tunnel achieves a cushion effect from the remnant PCL fibers, and this would reduce the killer-turn effect. The ratio between the total coronal length of the PCL fovea and the coronal tunnel position was 60.6% ± 20.4% in the current study. A slightly laterally (2 to 3 mm) positioned tibial tunnel can decrease the risk of graft impingement and the killer-turn effect.[28,52]

In the present study, common reasons for not returning to previous activity levels were apprehension (42.9%) and physical limits (35.7%) at 9 months after PCLR, and apprehension (57.1%) and problems unrelated to knee function (28.6%) at 24 months. At 9 months after PCLR, only 48% of the patients surveyed played with unlimited effort, unlimited performance, and no pain. In addition, the satisfaction scale (OR 2.8, 95% CI 1.186 to 10.281) was a significant factor associated with failure to return to preinjury levels of sports activity at the 9-month follow-up. These findings are of considerable importance when counseling patients on psychological readiness and sports experience, even after the return to any sports activity.

The strength of our study is that we evaluated the RTS after PCLR performed by a single surgeon using the same surgical indication and technique in a homogeneous group of patients. There is a paucity of information on rehabilitation and RTS after PCLR. We suggest that PCLR with remnant preservation, in which the graft is allowed to heal together with the remnant fibers and forms a broad cross-sectional area similar to that formed in double-bundle PCL, could represent a good strategy for high-demand patients, and early costrengthening of the quadriceps and hamstring muscles is an achievable target during rehabilitation.

Limitations

The present study has some limitations. First, this was a retrospective study with a limited follow-up, and there was no control group. Second, the quality of RTS was assessed only with a sports-experience questionnaire (comprising 5 classifications). Moreover, this sports-experience question has been used for anterior cruciate ligament reconstruction, not PCLR. Measurement of RTS or patient satisfaction after PCLR is not yet developed. Additional psychological and performance measurements are required to complement patient-reported outcome scores after PCLR.

Conclusions

Arthroscopic anatomic PCLR with remnant preservation showed high rates of RTS and high patient satisfaction, as well as satisfactory clinical results in highly active patients. This surgical technique could be an effective treatment for grade III PCL injury in highly active patients.

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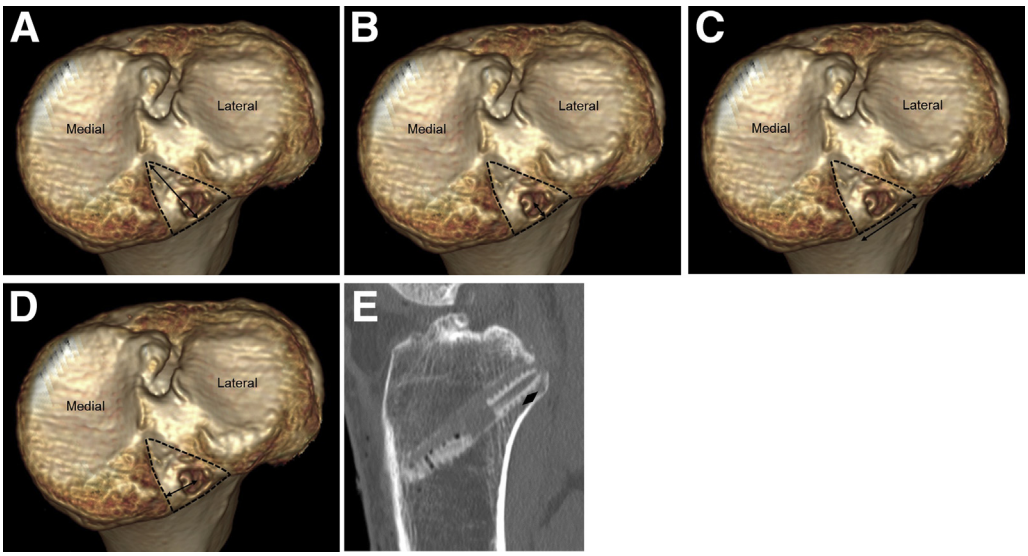
Appendix Table 1. Computed Tomography Evaluation of Tibial Tunnel

Parameter	Result
Total sagittal length of PCL fovea (mm)	19.4 ± 2.1
Sagittal tunnel position (mm)	6.2 ± 2.7
Total coronal length of PCL fovea (mm)	15.9 ± 1.8
Coronal tunnel position (mm)	9.8 ± 2.4
Ratio between total sagittal length of PCL fovea and sagittal tunnel position (%)	32.5 ± 15.4
Ratio between total coronal length of PCL fovea and coronal tunnel position (%)	60.6 ± 20.4
Length of posterior bone bridge (mm)	1.6 ± 0.9

NOTE. Data are mean ± standard deviation.
PCL, posterior cruciate ligament.



Appendix Figure 1. Five parameters are as follows. (A) Total sagittal length of the posterior cruciate ligament (PCL) fovea (sagittal distance from the posterior border of the tibial spine to the posterior margin of the PCL fovea). (B) Sagittal distance from the center of the tibial tunnel to the posterior margin of the PCL fovea (sagittal tunnel position). (C) Total coronal length of PCL fovea (coronal dimension of the PCL fovea from the medial margin to the lateral margin). (D) Coronal distance from the medial margin of the PCL fovea to the center of the tibial tunnel (coronal tunnel position). (E) Length of the posterior bone bridge (the nearest distance from the posterior border of the tibial tunnel to the posterior cortex). The dotted line describes the PCL fovea.