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Proprioception and Clinical Results of Anterolateral Single-Bundle Posterior Cruciate Ligament Reconstruction with Remnant Preservation

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Purpose: To evaluate the clinical and radiological results and proprioception following anterolateral single-bundle posterior cruciate ligament (PCL) reconstruction with remnant preservation for PCL injury.
Materials and Methods: Twenty patients with an isolated PCL injury (16 males and 4 females) were included in this study. The mean follow-up period was 61 months (≥24 months) and the mean age of the patients was 36 years. Knee joint instability was evaluated using posterior drawer stress radiography. Knee function, level of activities, and individual satisfaction were assessed using the Lysholm knee score, Tegner activity score, and 2000 International Knee Documentation Committee (IKDC) score. Knee proprioception was assessed using an isokinetic machine.
Results: The mean ligament laxity assessed using the posterior drawer stress radiography was improved from 10.8–3.2 mm. The mean Lysholm knee score was improved from 70.0–88.9 points, and the mean Tegner activity score was improved from 2.7–6.2 points. Individual satisfaction assessed using the IKDC score was improved from 62.7–85.4 points ($p<0.05$). Knee proprioception was not significantly different between the treated and the uninjured knees.
Conclusions: Single-bundle PCL reconstruction with remnant preservation for PCL injury exhibited satisfactory outcomes regarding functional outcome, joint stability, and proprioception.

Keywords: **Knee, Posterior cruciate ligament, Reconstruction, Remnant preservation, Proprioception**

Introduction

The posterior cruciate ligament (PCL) consists of anterolateral and posteromedial bundles that contribute to the structural stability of the knee by alternately becoming taut/loose during flexion/extension and play a major role in proprioception[1-3]. Thus, an injury to the PCL results in constant posterior instability of the knee, proprioception deficits due to the lack of information from mechanoreceptors, atrophy or muscle weakness, and knee joint degeneration[2].

The PCL has been known to have remarkable healing properties unlike the anterior cruciate ligament (ACL) because of the surrounding thick synovial sheath and its proximity to the branches of the middle genicular artery[4,5]. Accordingly, an isolated PCL injury was thought to heal satisfactorily with conservative treatment alone in the past[6-9]. However, long-term follow-up studies have demonstrated that persisting instability results in the development of patellofemoral or tibiofemoral arthritis and pain recurs due to untreated meniscal tears[10-12]. In addition, there has been much improvement in surgical techniques, and thus the interest in the surgical reconstruction of the PCL has been growing recently. The success rate of anterolateral single-bundle PCL reconstruction using various surgical techniques ranges from 41% to 72%[13-15]. In particular, remnant-preserving ligament reconstruction has gained considerable attention due to the advantages of graft revascularization and proprioception preservation, and excellent clinical results have been reported by many authors[16-19].

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These satisfying results can be attributed to the preservation of proprioception in the remnant ligament fibers according to studies on ACL reconstruction and total knee arthroplasty. In contrast, proprioception in PCL injured knees has been addressed in only a few studies and there is a paucity in the literature on the proprioceptive performance after PCL reconstruction[1,20]. In this study, we analyzed postoperative proprioception and clinical results of remnant-preserving reconstruction in PCL-deficient knees under the hypothesis that here would be no difference in the proprioceptive performance between the affected and unaffected knees.

Materials and Methods

1. Study Population

A total of 102 patients underwent PCL reconstruction between October 2004 and October 2009 at our institution. Of these, 58 patients were excluded due to the presence of combined injuries: an ACL tear in 19 patients, a medial collateral injury in 13 patients, a posterolateral collateral ligament tear in 14 patients, and a femoral or tibial fracture in 12 patients. Of the remaining 44 patients who had undergone remnant-preserving anterolateral single-bundle PCL reconstruction with the trans-tibial tunnel technique, 20 patients who were available for ≥2 years of follow-up and clinical and functional assessments were included in this study. Although meniscus tears were observed in 3 patients (a medial meniscus tear in 2 and a lateral meniscus tear in 1), no additional treatment was necessary due to the minor nature of the injury. The mean follow-up period was 61.3 months (range, 31 to 92 months). There were 16 males and 4 females with a mean age of 36 years (range, 17 to 60 years). The preoperative posterior drawer test demonstrated grade II ligament laxity in 12 patients (60%) and grade III laxity in 8 patients (40%). The mechanism of injury was a car accident in 6 patients, a motorcycle accident in 6 patients, a sports injury in 4 patients, and a direct injury in 4 patients. An Achilles tendon allograft was used to reconstruct the PCL in all patients.

2. Surgical Technique

The indications for surgery were ≥grade II severe ligament laxity in the posterior drawer test following ≥6 months of conservative treatment and a PCL injury with severe pain that restricts normal daily activities[13]. The patient was placed in the supine position and a tourniquet was applied. The uninjured limb was kept in the lithotomy position to allow for the placement of an image intensifier. An arthroscopic examination was performed to identify the extent of PCL injury and knee joint damage. The anterolateral bundle was reconstructed using a single-bundle technique, taking care to preserve the remnant of the torn ligament as much as possible. With guide pins inserted into the surrounding tissue, the periosteum at the femoral tunnel site was stripped off as much as possible with a narrow osteotome to prevent damage from a reamer during tunneling. A tibial tunnel was created with a 0.5 mm increment from 6mm using a drill guide and a reamer that was rotated counterclockwise under the guidance of an image intensifier to protect the nerves and vessels in the posterior tibia.

The femoral tunnel was drilled inside-out at a site 5–6 mm proximal to the articular cartilage at a 1 o'clock angle for the right knee and an 11 o'clock angle for the left knee, taking care to minimize the risk of impingement. The entry of the tibial tunnel was placed 10–15 mm below the articular surface and a guide pin was inserted from a site immediately lateral to the tibial attachment of the PCL. An Achilles tendon allograft with a thickness of 10 mm was attached to a wire loop, inserted through the anterolateral portal of the femoral tunnel above the remaining tissue. With the graft fixated to the femur using absorbable interference screws, flexion/extension exercises were performed for 15 times. With the knee in 90^o flexion, the graft in the tibial tunnel was fixated using a bioabsorbable screw and a cancellous screw and s washer.

Postoperatively, long leg cast immobilization was applied with the knee in extension for 3–4 weeks. At 4–6 weeks postoperative, passive flexion exercises and weight-bearing with crutches were initiated. Flexion with the aid of a device was gradually increased to 90^o–100^o by 6–8 weeks postoperatively. Running was gradually allowed from 8–10 weeks postoperative and return to sports activities was permitted 12 months postoperatively.

3. Clinical and Radiological Assessments

The clinical assessment was performed using the Lysholm knee score, Tegner activity score[21], and 2000 International Knee Documentation Committee (IKDC) subjective knee score preoperatively and at the last follow-up. The radiological outcome was assessed using posterior drawer stress radiography. The radiographs were taken with the knee in 90^o flexion while posteriorly directed force was applied by the Telos Stress Device (METAX, Hungen, Germany). The radiographs of the injured and uninjured limbs obtained preoperatively and at the last follow-up were compared.

4. Proprioceptive Evaluation

Proprioceptive evaluation was based on the kinesthesia and joint position sense at the last follow-up. Kinesthesia was assessed by measuring the threshold to detect passive movement (TTDPM) and the joint position sense was assessed by reproduction of passive positioning (RPP).

For the proprioceptive evaluation of the knee, TTDPM and RPP were assessed using the Biodex System 4 (Biodex Medical Systems, Shirley, NY, USA). The patient was seated in a chair with the trunk, thigh, and ankle strapped with belts to the chair. To reduce cutaneous input, the patient was wearing a pneumatic compression boot and shorts during the examination. To eliminate visual and auditory cues, the patient was wearing a blindfold and a headset playing white noise (Fig. 1). The tests were performed by moving the knee into flexion and extension from two starting positions, 45° and 110°. This was because the lowest proprioception was considered to be measured in 45° of flexion where the capsule, ACL, and PCL are relatively relaxed, whereas PCL was thought to start to play a role in proprioception when the knee is in 110° flexion due to tension on the ligament[20]. The knee was flexed/extended at a velocity of 1°/s at the starting positions.

1) Threshold to Detect Passive Movement

TTDPM was assessed by asking the patient to press a switch upon perception of sensation of movement of the knee during passive flexion/extension from the two starting positions, 45° and 110°. The tests were performed three times each for the injured and uninjured knees. The mean values of the angular differences from the starting positions were recorded.

Fig. 1. The evaluation of proprioception. The patient is sitting wearing a pneumatic compression boot, a blindfold to eliminate visual cue, and a headset to eliminate auditory cues.

2) Reproduction of Passive Positioning

The knee was flexed/extended passively from 45° and 110° and held for 10 seconds at a targeted angle by the tester for the patient to remember the positions. Then, the knee was returned to the starting positions. While the tester was extending/flexing the patient's knee, the patient was asked to press a switch when he or she felt the knee was moved to the targeted angle. The targeted angle was 35° of extension and 55° of flexion from the starting point of 45°, whereas 100° of extension and 120° of flexion from the starting point of 110°. The test was performed three times each for the injured and uninjured knees. The mean values of the differences between the targeted angles and the angles repositioned by the patient were recorded.

The values from the injured and uninjured knees in both groups were analyzed using the SPSS ver. 18.0 (SPSS Inc., Chicago, IL, USA). The Mann-Whitney test was used for non-normal distribution data and the t-test was used for normal distribution data. A paired t-test was used for the comparison of the pre-and postoperative values and the proprioception was compared using an independent t-test. A p-value of <0.05 was considered statistically significant.

Results

The mean Lysholm score was significantly improved from 70.00±6.89 (range, 53 to 81) preoperatively to 88.90±4.36 (range, 85 to 95) at the last follow-up (p=0.00) (Table 1).

A remarkable increase was noted in the mean Tegner activity score from 2.70±0.92 (range, 1 to 4) preoperatively to 6.20±1.32 (range, 4 to 8) at the last follow-up (p=0.00).

The mean 2000 IKDC subjective knee score was significantly improved from 62.72±10.53 (range, 29.9 to 73.5) preoperatively to 85.41±7.97 (range, 65.5 to 95.4) at the last follow-up (p=0.00). The preoperative IKDC score was abnormal in 12 patients (60%) and severely abnormal in 8 patients (40%) and the score at the last follow-up was normal 8 (40%) patients and nearly normal in 12 patients (60%) (Table 2).

The mean side-to-side difference on the posterior drawer stress

Table 1. Change of Lysholm Knee Score

	Preoperative	Last follow-up
Excellent (100–95)	0	6
Good (94–84)	0	14
Fair (83–65)	16	0
Poor (64–0)	4	0
Mean Lysholm score	70.0	88.9

Table 2. Change of 2000 International Knee Documentation Committee Knee Evaluation

	Preoperative	Last follow-up
A (normal)	0	8
B (nearly normal)	0	12
C (abnormal)	12	0
D (severely abnormal)	8	0

Table 3. Change of Ligament Laxity

	Preoperative	Last follow-up
Grade 1	0	20
Grade 2	12	0
Grade 3	8	0
Mean ligament laxity (mm)	10.8	3.2

radiographs was decreased from 10.80±1.50 mm (range, 9 to 13 mm) preoperatively to 3.20±1.36 mm (range, 1 to 5 mm) at the last follow-up, indicating statistically significant improvement (p=0.00). The ligament laxity was grade II in 12 patients (60%) and grade III in 8 patients (40%) preoperatively, whereas grade I in all patients at the last follow-up (Table 3).

The mean TTDPM from 45° toward extension was 1.57±0.61 for the injured side and 1.35±0.35 for the uninjured side, and the value toward flexion was 1.72±0.62 for the injured side and 1.47±0.33 for the uninjured side. The mean TTDPM from 110° toward extension was 1.50±0.45 for the injured side and 1.37±0.37 for the uninjured side, and the value from 110° toward flexion was 1.58±0.61 for the injured side and 1.37±0.30 for the uninjured side. Although the TTDPM was more improved in the injured than the uninjured side, no significant side-to-side difference was observed (Table 4).

The mean RPP for extension from 45° was 2.18±1.03 for the injured side and 1.82±0.99 for the uninjured side, and the value for flexion from 45° was 2.52±1.33 for the injured side and 1.87±0.74 for the uninjured side. The mean RPP for extension from 110° was 2.43±1.18 for the injured side and 2.28±0.84 for the uninjured side, and the value for flexion from 110° was 2.83±1.50 for the injured side and 2.17±1.09 for the uninjured side. Although the RPP was more improved in the injured than the uninjured side, no significant side-to-side difference was observed (Table 4).

Discussion

The hypothesis of our study was that remnant-preserving PCL reconstruction would be effective in restoring knee function and

Table 4. Proprioception Evaluation

Test	PCL reconstruction knee	Uninjured knee
TTDPM		
45° extension	1.57±0.61	1.35±0.35
45° flexion	1.72±0.62	1.47±0.33
110° extension	1.50±0.45	1.37±0.37
110° flexion	1.58±0.61	1.37±0.30
RPP		
45° extension	2.18±1.03	1.82±0.99
45° flexion	2.52±1.33	1.87±0.74
110° extension	2.43±1.18	2.28±0.84
110° flexion	2.83±1.50	2.17±1.09

PCL: posterior cruciate ligament, TTDPM: threshold to detect passive movement, RPP: reproduction of passive positioning.

proprioception to the level of the intact knee. The study results showed that the knee function was improved postoperatively and the postoperative proprioception was similar to that of the uninjured knee.

Various authors have introduced remnant-preserving PCL reconstruction techniques that provide satisfying clinical results. Jung et al.[22] performed tensioning of the remnant PCL and reconstruction of the anterolateral bundle of the PCL using a modified inlay technique, and reported that the IKDC score at the last follow-up was nearly normal in 87.7% and posterior tibial translation on posterior stress radiographs was ≤5 mm in all cases. In a study by Zhao et al.[23] sandwich-style double-bundle PCL reconstruction yielded higher than nearly normal IKDC score and ≤5 mm posterior tibial translation in all cases at the last follow-up. According to Ahn et al.[16] trans-tibial PCL reconstruction with preservation of the remnant PCL fibers resulted in successful clinical outcomes. In the study, the mean Lysholm score was improved from 65.8 preoperatively to 92.9 at the last follow-up, the IKDC subjective evaluation score was higher than nearly normal in all cases at the last follow-up, the objective evaluation score was higher than nearly normal in 97% of the cases, and posterior tibial translation was ≤5 mm in 97% of the cases at the last follow-up. In addition, preservation of the original PCL fibers was effective in reducing the killer turn effect. In our study, the clinical outcomes of trans-tibial remnant preserving PCL reconstruction were satisfying: the Lysholm score was similar to those in previous studies, the IKDC score was improved, and posterior tibial translation was ≤5 mm in all knees.

The PCL contains mechanoreceptors, such as Pacinian corpuscles, Ruffini's corpuscles, Golgi organs, and free nerve endings[24,25]. Pacinian corpuscles are the largest receptors that rapidly detect joint movements and have a low threshold for activation. Ruffini's corpuscles slowly respond to changes in ligament tension and are responsible for pressure reception. Free nerve endings act as pain sensors[2,26]. Mechanoreceptors that detect knee joint positions and changes in muscle tension and velocity send afferent messages to the central nervous system and receive efferent messages for joint movement, contributing to joint stability and injury prevention[2,27]. These mechanoreceptors can be evaluated using the passive motion threshold test and the passive joint position sense test. In a study by Clark et al.[1] the passive motion threshold test with 37° set as a starting position demonstrated that PCL-deficient knees had reduced proprioception compared to the intact knees. Safran et al.[20] tested the threshold to detect passive motion and the ability to reproduce passive joint position from 2 starting positions, 45° and 110°, in chronic PCL-deficient knees. In the study, the threshold to detect passive motion was reduced at 45° in the PCL-deficient knees. On the other hand, the ability to reproduce passive joint position was significantly better in the PCL-deficient knees, which can be attributed to the influence of the ACL on proprioception, improved sensation after physical therapy, or the different mechanisms of the joint motion sense and the joint position sense[20]. In our study, the TTDPM and RPP that were evaluated from two starting positions, 45° and 110°, after remnant-preserving PCL reconstruction were reduced in the PCL-deficient knees, but the side-to-side differences were statistically insignificant. In a study by Adachi et al.[28] on the joint position sense after PCL reconstruction, the authors reported that the joint position sense that had worsened immediately after reconstruction was gradually recovered from 18 months postoperatively to the preoperative level at 24 months postoperative. In our study, the proprioception of the injured knees became similar to that of the uninjured knees at the last follow-up, although the changes during the follow-up period were not assessed.

Solomonow and Krogsgaard[29] reported that mechanoreceptors are mostly present at the ligament insertion points that are firm and safe from constant changes. According to Lopes et al.[30] the mean distance from the margin of the femoral plane to the center of the anterolateral insertion is 7 mm and to the center of the posteromedial insertion is 8 mm. Tajima et al.[31] reported that the mean distance from the margin of the tibial plane to the center of the anterolateral insertion is 1.5 mm and to the center of the posteromedial insertion is 6 mm and the mean distance from the medial margin of the tibia to the center of the anterolateral insertion is 47% and to the center of the posteromedial insertion is 43.8%. In our study, the remnant PCL fibers were peeled off as much as possible to preserve proprioception and tunneling was started 5–6 mm below the femoral articular surface and 10–15 mm below the tibial articular surface that is immediately lateral to the tibial attachment of the PCL during PCL reconstruction.

The limitations of this study include that the small number of study population may have caused statistical errors and the influence of combined meniscal or cartilage damage was not reflected in the study results. There were no comparisons on proprioception between the injured knees and the intact knees and between the preoperative and postoperative conditions. The results of PCL reconstruction for chronic PCL injury were not compared with those of conservative treatment. As the study population consisted of those who underwent remnant-preserving PCL reconstruction, there was no comparison with the patients in whom the remnant fibers were removed during surgery. Lastly, the influence of the difference in the amount of the remnant fibers on the treatment results was not addressed due to the difficulty of quantification.

Remnant-preserving PCL reconstruction resulted in satisfying clinical and radiological outcomes. The postoperative proprioception was reduced in the treated knees compared to the intact knees, but the difference was not statistically significant. Considering that the proprioception of the reconstructed knees was similar to that of the intact knees, remnant-preserving PCL reconstruction could be advantageous for preservation and restoration of proprioception. However, we believe that these findings should be confirmed in further studies involving larger study populations and more systematic analyses.

Conclusions

We believe that remnant-preserving anterolateral single-bundle PCL reconstruction could be a promising method for the treatment of isolated PCL injury based on our findings that the postoperative knee joint function and radiological results were satisfactory and the postoperative proprioception of the treated knees was similar to that of the intact knees.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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