

Temporal change of joint position sense after posterior cruciate ligament reconstruction using multi-stranded hamstring tendons

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Abstract A total of 29 patients who had undergone posterior cruciate ligament (PCL) reconstruction using multi-stranded hamstring tendons were prospectively followed-up for joint stability and proprioceptive function at a minimum of 24 months after surgery. We measured temporal changes of the posterior laxity by stress radiography and the KT-2000 arthrometer, and we also measured joint position sense for an average of 42 months (range 24–78 months). In terms of results, improvement of joint stability was observed postoperatively and maintained over 2 years after PCL reconstruction, although posterior stability in the reconstructed knee was not identical to the contralateral normal knee. Although joint position sense worsened just after reconstruction, it gradually recovered from 18 months after surgery. However, proprioceptive function after PCL reconstruction did not recover to the same level as in the contralateral normal knee even over 24 months after surgery.

Keywords Posterior cruciate ligament · Joint position sense · Proprioceptive function · Reconstruction · Hamstring

Introduction

The posterior cruciate ligament (PCL) may have two important functions: mechanical and proprioceptive. Although mechanical functions of normal PCL or reconstructed PCL have been well studied for many years [9, 12, 13, 18, 19], recently orthopaedic knee surgeons have focused on their proprioceptive functions. In 1984, Schultz et al. [26] histologically confirmed the existence of mechanoreceptors in the human cruciate ligament and suggested their proprioceptive role. It is now well recognized that normal cruciate ligaments are extensively innervated by mechanoreceptors with important afferent functions [15, 17].

As for the regeneration of mechanoreceptors in the reconstructed cruciate ligaments, the reinnervation of mechanoreceptors was histologically confirmed in the reconstructed anterior cruciate ligament (ACL) of the experimental model [8, 27]. In clinical studies, Ochi et al. [22, 23] found detectable somatosensory evoked potential in the reconstructed ACL with autologous hamstring tendons by electrical and mechanical stimulations, suggesting that sensory innervation can occur in the reconstructed ACL. In 2000, Iwasa et al. [14] investigated the postoperative improvement of the proprioceptive function in the knee with ACL reconstruction, indicating the regeneration of mechanoreceptors in the reconstructed ACL. Thus, it is now believed that reconstructed cruciate ligaments also provide proprioceptive function through the regeneration of mechanoreceptors in the reconstructed ligament. Thus, although there have been many reports on the proprioceptive function about ACL, until now there have been few reports that have clarified postoperative proprioceptive function after PCL reconstruction. The

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purposes of this study were to evaluate the temporal change of the postoperative joint position sense and the joint laxity after PCL reconstruction using multi-stranded hamstring tendons and to evaluate the correlation between the joint position sense and the joint laxity or clinical results.

Materials and methods

The review board at our institution approved the use of human subjects for this research. Before performing this study, written informed consent was obtained from all patients and the rights of the patients were protected.

Indication for PCL reconstruction

In a previous study, we investigated temporal change of posterior laxity in fresh, isolated PCL-injured knees [2]. We confirmed that in some patients, although the posterior laxity was severe at the initial consultation, it improved at 6 months after injury and was constant thereafter. We concluded that fresh, isolated PCL injury should be treated conservatively for at least 6 months after injury, even if the posterior laxity was severe at the initial consultation. Therefore, our indication for PCL reconstruction was patients with severe posterior laxity, which was 8 mm more than in the contralateral normal knee despite several conservative treatments for at least 6 months.

Patients

At the first visit, a routine physical examination for PCL injury, such as the posterior sagging sign, the posterior drawer test, and the quadriceps drawer test, were performed. To examine PCL injuries associated with posterolateral corner injury and posteromedial injury, varus and valgus instability tests and the posterolateral and the posteromedial drawer tests were performed. The external rotation recurvatum test and the reversed pivot-shift test were used to evaluate posterolateral instability. Thus, PCL injuries associated with posterolateral corner injury and posteromedial injury were excluded, and only patients with isolated PCL injury remained as subjects in this study.

From 1998 to 2001, 36 patients underwent single-bundle PCL reconstruction for isolated PCL injury using multi-stranded autologous hamstring tendons. Among them, patients who had a history of contralateral knee injury or knee surgery, or patients who had severe osteoarthritic changes (more than 50% of joint space narrowing in any compartment) were excluded

from this study. Three patients were excluded from this study because they were not available for follow-up at the required periods after surgery. After these exclusions, 29 patients were included in this study. They were 22 males and seven females with a mean age of 31.9 (17–54) years at the time of surgery. Causes of injury were traffic accident in 14 patients, sports-related injury in 13 patients, and a fall in two patients. The average periods from the initial injury to the operation were 10.2 months (range 6 months to 3 years and 3 months). The average postoperative follow-up periods were 42 months (range 24–78 months).

Operative techniques

Graft harvest and preparation

Both the semitendinosus and gracilis tendons were harvested with an open tendon stripper. We usually tripled or quadrupled the tendons to make them more than 8 mm in diameter and more than 75 mm in length. The average diameter of the proximal side of the graft measured by the sizing tubes was 9.2 ± 1.0 mm (8–10). The proximal ends of the multi-stranded hamstring tendons were connected with Endobutton CLTM (Acufex, Smith & Nephew, Mansfield, MA, USA), and the distal ends were sutured with Endobutton TapeTM (Acufex, Smith & Nephew, Mansfield, MA, USA).

Tunnel creation, graft passage, and fixation

We performed PCL reconstruction with the bone tunnel technique. The posterior opening of the tibial drill hole was within the distal area of PCL tibial attachment. A femoral bone tunnel was created in the inside-out fashion. The point of the femoral bone tunnel in the intercondylar space was 5 mm posterior from the articular margin and 5 mm distal from the Blumensaat line. The length of the femoral socket should be at least 15 mm (9 mm for the graft and 6 mm for the Endobutton turning). After the graft was passed through the tibial tunnel to the femoral socket, the Endobutton was flipped and fixed on the medial cortex of the femur. The graft excursion was checked. In all cases, the graft was pulled into the tibial tunnel with the knee approaching full flexion. The total length of the excursion of the graft was 3.3 ± 1.4 (1.0–5.0) mm. While applying manual maximum tension to the distal Endobutton Tape of the graft, it was fixed with double spike staples with the knee at a 90° flexed position.

Postoperative rehabilitation

Active quadriceps exercises were recommended as soon as possible after the operation. After the knee was immobilized for 1 week with the knee braced at extension, range of motion exercises were initiated using a continuous passive motion device. Weight bearing was permitted 3 weeks after the operation. Jogging was permitted after 4 months, and strenuous sports activities were allowed starting 12 months after surgery.

Objective evaluations

The evaluation of joint laxity and joint position sense was performed preoperatively, at 6, 12, 18, and 24 months after surgery, and at the final follow-up which was more than 24 months after surgery. We did not evaluate joint laxity and position sense at 3 months after reconstruction, because some patients showed postoperative disturbance of range of motion at 3 months after surgery.

At the first consultation, a lateral radiograph of both knees flexed at 90° was taken with manual maximum posterior stress to the proximal tibia. Posterior laxity was examined using this lateral radiograph. In the actual measurement, the most anterior tip (A) and the most posterior tip (B) of the tibia were determined. Straight lines were drawn parallel to the baseline (AB) and tangential to the medial and lateral femoral condyles. From the points of contact on the femoral condyles, perpendicular lines were drawn to the base line. From their feet on the base line (M and L), the midpoint (C) was obtained. The difference, in millimetres, between AC in the contralateral normal knee and AC in the injured knee was calculated (Fig. 1). Because 1 mm is magnified to 1.1 mm on radiographs, the measurement of the side-to-side difference was divided by 1.1.

In addition to the radiographs, the KT-2000 knee arthrometer test was performed on each patient in the standard fashion. After applying a posterior load of 89 N and an anterior load of 133 N with the knee flexed at 70°, total displacement was measured, and the relative translation was calculated, in millimetres, by subtracting the amount of translation of the contralateral normal knee from the injured knee.

We compared the preoperative posterior laxity to that at every evaluation point after surgery. The laxity of the reconstructed knee was also compared to that in the contralateral normal knee at every evaluation point after surgery. When performing posterior laxity testing, we advised the patients to be relaxed to reduce muscle

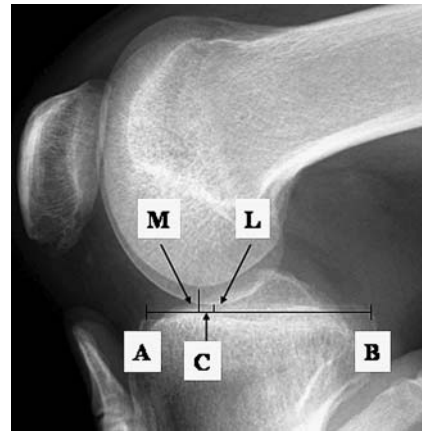


Fig. 1 Lateral radiograph of both knees flexed at 90° is taken with manual maximum posterior stress to the proximal tibia. The most anterior tip (A) and the most posterior tip (B) of the tibia are determined. Straight lines are drawn parallel to the baseline (AB) and tangential to the medial and lateral femoral condyles. From the points of contact on the femoral condyles, perpendicular lines were drawn to the base line. From their feet on the base line (M and L), the midpoint C is obtained. The difference, in millimetres, between AC in the contralateral normal knee and AC in the injured knee is calculated. Because 1 mm is magnified to 1.1 mm on radiographs, the measurement of the side-to-side difference is divided by 1.1 and the result is determined to be the posterior laxity

contraction, although we did not measure the muscle contraction quantitatively.

Joint position sense tests evaluate the ability of patients to reposition their knee to a previously placed angle. The test was performed according to Skinner's [29] method using a Cybex II dynamometer (Cybex Co., Division of Lumex, Ronkonkoma, NY, USA). The patients sat on the seat of the Cybex apparatus with their shoulders, chest, pelvic region, and thigh immobilized with straps. The position of the seat was adjusted so that the axis of knee flexion and extension of the knee were brought into the same axis as the dynamometer of the Cybex apparatus. The lower leg was immobilized on a pad with straps so that the distal edge of the pad was level with the ankle joint. They were blinded with eye mask and acoustic information was shut down with headphones. The information from the skin sensation was minimized with inflated boots. The order of the tested knee was selected randomly. First, an examiner extended the knee of the sitting patient at a slow steady rate of approximately 10°/s from the 90° starting position. The leg was then stopped at a random angle between 35° and 80° and held by the examiner for 3 s. The patients were asked to remember the position of the leg. The knee was then returned to the starting angle, and the patient was

asked to return the leg to the previous position. This measurement was conducted in both knees 10 times. The average inaccuracy was calculated for each knee. The final inaccuracy was expressed as the difference between the mean score for the injured knee and the mean score for the normal knee. We compared the preoperative final inaccuracy of the joint position sense to that at every evaluation point after surgery. The average inaccuracy of the joint position sense of the reconstructed knee was also compared to that in the contralateral normal knee at every evaluation point after surgery.

The clinical results were evaluated using Lysholm score preoperatively and at the final follow-up. We also evaluated the relationship between the posterior laxity or Lysholm scores and joint position sense at the final follow-up.

One of our authors who was blind to the groups, and demographics of the patient performed all tests for posterior laxity and joint position sense.

Statistical analysis

The Wilcoxon signed rank test was used for paired comparison of joint laxity or Lysholm score and joint position sense. Spearman's correlation coefficient was calculated for the relationship between the posterior laxity and the joint position sense. We used an alpha level of 0.05 for all statistical tests. All statistical analyses were conducted on Statview 5.0[®] (SAS Institute, Cary, NC, USA).

Results

Posterior laxity measured by stress radiography

The temporal change of posterior laxity measured by stress radiography is shown in Fig. 2. Posterior laxity preoperatively, at 6, 12, 18, and 24 months after surgery, and the final follow-up were 9.8 ± 2.3 , 2.8 ± 2.8 , 3.3 ± 3.3 , 3.4 ± 2.5 , 3.6 ± 2.4 , and 3.5 ± 2.7 , respectively. There was a statistically significant difference between the preoperative posterior laxity and other time points, showing postoperative improvement of posterior laxity ($p < 0.01$). However, posterior laxity of the reconstructed knee was not statistically identical to the contralateral normal knee at every evaluation point.

Posterior laxity measured by KT-2000

The temporal change of the posterior laxity measured by the KT-2000 is shown in Fig. 3. The posterior laxity

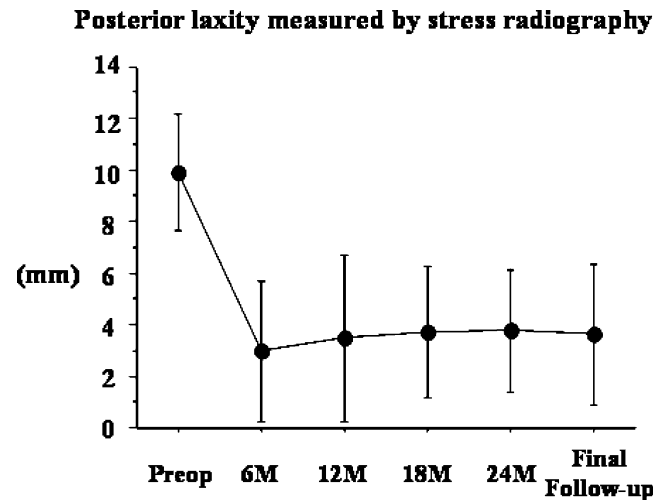


Fig. 2 Temporal change of posterior laxity measured by stress radiograph. There is a statistically significant difference between the preoperative posterior laxity and other time points, showing postoperative improvement of posterior laxity ($p < 0.01$)

preoperatively at 6, 12, 18, and 24 months after surgery, and at the final follow-up were 9.3 ± 2.2 , 3.1 ± 3.1 , 3.6 ± 2.1 , 3.6 ± 2.6 , 3.5 ± 2.9 , 3.7 ± 2.4 , respectively. There was a statistically significant difference between the preoperative posterior laxity and other time points, showing postoperative improvement of the posterior laxity ($p < 0.01$). However, posterior laxity of the reconstructed knee was not statistically identical to the contralateral normal knee.

Joint position sense

The temporal change of the final inaccuracy of joint position sense is shown in Fig. 4. Although the final

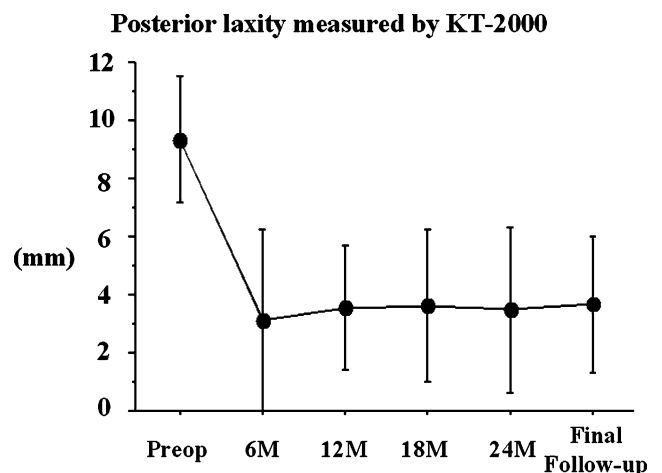


Fig. 3 Posterior laxity measured by KT-2000. There is a statistically significant difference between the preoperative posterior laxity and other time points, showing postoperative improvement of total displacement of the tibia ($p < 0.01$)

inaccuracy of the joint position sense increased at 6 and 12 months, it improved thereafter. The final inaccuracy of the joint position sense at 18 and 24 months after reconstruction and final follow-up were not statistically different from that preoperatively, showing postoperative worsening and improvement. However, the average accuracy in the PCL-reconstructed knee was not statistically identical to that in the contralateral normal knee even at the final follow-up.

There was no statistically significant relationship between the final inaccuracy of joint position sense and posterior laxity measured by stress radiographs or the KT-2000 knee arthrometer at the final follow-up. The average Lysholm scores preoperatively and at the final follow-up were 69.6 ± 6.3 and 94.6 ± 4.4 , respectively. Lysholm score improved significantly postoperatively. However, there was no statistically significant relationship between the final inaccuracy of joint position sense and Lysholm scores at the final follow-up.

Discussion

As shown in this study, we confirmed postoperative improvement of posterior laxity in the knee with PCL reconstruction using multi-stranded hamstring tendons, although the posterior stability was not identical to the contralateral normal knee. This study also clearly demonstrated that the proprioceptive function after PCL reconstruction measured by joint position sense deteriorated after reconstruction, and then showed postoperative improvement from 18 months after surgery. However, the postoperative joint position sense

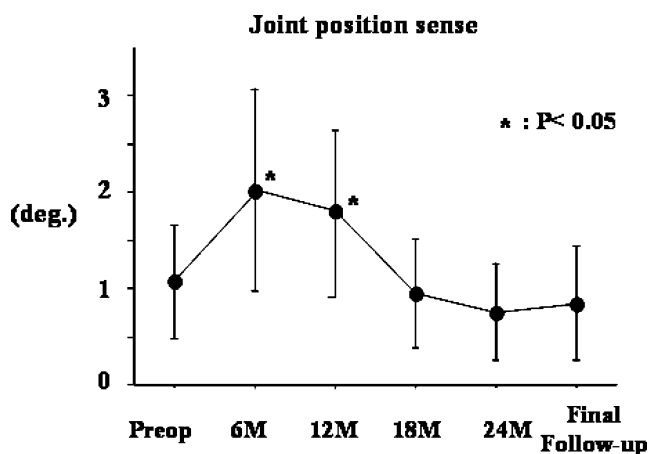


Fig. 4 The temporal change of the final inaccuracy of joint position sense. Although the final inaccuracy of joint position sense is significantly increased at 6 and 12 months after reconstruction, it improves thereafter. The final inaccuracy of the joint position sense at 18 and 24 months after reconstruction and final follow-up are not statistically different from that preoperatively ($p < 0.01$)

did not recover to the normal level even over 2 years after PCL reconstruction.

PCL is the main restraint to posterior translation of the tibia. Although PCL injury is less common than ACL injury, patients who have severe posterior laxity complain of instability of the knee during sports activities or daily lives. Treatment options for PCL injury consist of conservative treatment and operative treatment, that is, PCL reconstruction. It is well recognized that isolated PCL injury does well with conservative treatment [6, 24, 28]. However, more recent studies with longer follow-up periods have reported a gradually increased incidence of secondary chondral lesions and eventually osteoarthritic changes [3, 4, 7, 16]. It has also been reported that isolated PCL injury can adversely affect other knee ligaments [20, 21]. As a matter of fact, many orthopaedic surgeons usually treat a displaced PCL avulsion fracture surgically. This means that selection of conservative treatment may be due to the fact that, unlike with ACL reconstructions, no PCL reconstructions secured good stability and range of motion of the knee simultaneously. Recently, PCL reconstruction has been improving through an increased number of studies on PCL anatomy and biomechanics, and through innovation of surgical instruments [10, 11, 25]. We have performed PCL reconstruction using multi-stranded hamstring tendons and the bone tunnel technique.

After Schultz et al. [26] reported the existence of mechanoreceptors in the human cruciate ligament and suggested their proprioceptive role, others reported similar findings. As for the mechanoreceptors in PCL, Katonis et al. [15] histologically identified Ruffini's corpuscles, Pacini corpuscles, and free nerve endings in the healthy human PCL. They described the afferent role of PCL to the central nervous system. It is now accepted that the normal cruciate ligament is extensively innervated by mechanoreceptors with important afferent functions. Recently, more attention has been focused on this proprioceptive function of PCL as well as of ACL.

In 1996, Clark et al. [5] investigated the proprioceptive function in patients with PCL-injured knees. They demonstrated a significant loss of proprioceptive function measured by the threshold to detection of passive motion (TTDPM) in the PCL-injured knees compared with the contralateral normal knees. Similarly, in 1999, Safran et al. [25] demonstrated a statistically significant reduction in TTDPM in PCL-injured knees tested from a 45° starting position, moving into flexion and extension.

Regarding the regeneration of mechanoreceptors in the reconstructed cruciate ligament, the reinnervation

of mechanoreceptors was histologically confirmed in the reconstructed ACL of the experimental model using sheep, rabbit, and dogs [8, 27]. Ochi et al. [22, 23] found detectable somatosensory evoked potential in the reconstructed ACL with autogenous hamstring tendons by electrical and mechanical stimulations, suggesting that sensory innervation can occur in the reconstructed ACL. Thus, it is now believed that reconstructed ACL also provides proprioceptive function through regeneration of mechanoreceptors in the reconstructed ligament. As for clinical studies on the proprioceptive function after cruciate ligament reconstruction, in 2000, Iwasa et al. [14] investigated the postoperative improvement of the proprioceptive function in the knee with ACL reconstruction. Their results indicated that 30 of 38 patients with ACL reconstruction improved their position sense from 18 months to the final follow-up, indicating regeneration of mechanoreceptors in the reconstructed ACL. However, there have been few reports on the postoperative proprioceptive function after PCL reconstruction.

As shown in this study, the proprioceptive function measured by the joint position sense after PCL reconstruction worsened soon after reconstruction, but it then recovered gradually. However, it did not recover to the same level to the contralateral normal knee even over 2 years after reconstruction. There is a possible explanation of the loss of proprioceptive function soon after reconstruction. Normal PCL is usually well covered with synovium compared to the ACL. Even in patients with severe posterior laxity due to PCL injuries, we can observe some extent of PCL remnants under arthroscopy when PCL reconstruction. However, in this series of PCL reconstructions, the PCL remnants with surrounding synovium were almost completely resected. Because the resecting PCL remnants might cause a loss of mechanoreceptors, which exist in the ligament or synovium, the proprioceptive function soon after PCL reconstruction might deteriorate. As we reported previously, ACL augmentation in which ACL remnant with mechanoreceptors were preserved could facilitate the postoperative proprioceptive function [1]. Therefore, to reduce the loss of proprioceptive function after PCL reconstruction, another PCL augmentation procedure in which PCL remnants with mechanoreceptors is preserved may be necessary.

The fact that it was necessary for 18 months after PCL reconstruction to recover proprioceptive function was very consistent with Iwasa's report on recovery of proprioceptive function after ACL reconstruction using hamstring tendons. They investigated the post-

operative improvement of proprioceptive function in the knee with ACL reconstruction. As they described in their study, abnormal proprioceptive function of the knee can be induced by the loss of mechanoreceptors of the injured ligament, or abnormal neurologic output from deformed joint capsule or remaining ligaments due to ligamentous instability. If the preoperative poor proprioceptive function was through the abnormal afferent information due to deformed joint capsules or other ligaments, the proprioceptive function should have recovered soon after reconstruction in which a normal relationship between the femur and tibia was restored by the reconstruction. Considering the fact that some extent of recovery of the proprioceptive function required 18 months after reconstruction, the regeneration of mechanoreceptors may affect the recovery of the proprioceptive function of the knee.

Although we observed some extent of improvement of joint position sense postoperatively, we should recognize that the proprioceptive function did not recover to the level of the normal knee even over 2 years after reconstruction. The bigger size and longer length of the graft compared to the ACL reconstruction may be one factor to affect the results. The biomechanical environment after PCL reconstruction, which affects the regeneration of mechanoreceptors, may also differ from that in the ACL reconstruction. The other explanation is that we did not adopt proprioceptive rehabilitation postoperatively. Therefore, there would be a possibility that proprioceptive function could improve through postoperative proprioceptive rehabilitation. Further clinical study including proprioceptive rehabilitation will be definitely necessary to clarify this matter.

For evaluating the joint laxity and joint position sense, we used the contralateral knees as control. However, it is well known that the contralateral uninjured knee of the ACL-injured patients are not normal compared to healthy volunteers. However, because we did not have comparable data of healthy volunteers, we adopted the contralateral knees as control.

When performing the joint position sense test, we could not control muscle contraction. Because muscle spindles also have important proprioceptive function, there is great possibility that not only the neural elements in the PCL graft, but also muscle spindle could affect the proprioceptive function during the joint position testing. Further proprioceptive evaluation in which muscle contraction is minimized is necessary.

Before this study, we speculated that the proprioceptive function after PCL reconstruction would be related to posterior stability, because good stability of

the joint usually related to good ligament tension or synovial coverage of the reconstructed ligament, which could provide good generation of mechanoreceptors. However, our results showed that there was no significant relation between the joint stability and joint position sense.

In conclusion, we demonstrated a temporal change of proprioceptive function after PCL reconstruction using multi-stranded hamstring tendons. The proprioceptive function deteriorated soon after reconstruction and it recovered gradually from 18 months after reconstruction. However, it did not recover to the same level as the normal knee even over 2 years after reconstruction. We should recognize that the proprioceptive function after PCL reconstruction using multi-stranded hamstring tendons did not recover to normal level, unlike after ACL reconstruction.

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