Original Research

Tunnel Enlargement Correlates With Postoperative Posterior Laxity After Double-Bundle Posterior Cruciate Ligament Reconstruction

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Background: There exists little information in the relevant literature regarding tunnel enlargement after posterior cruciate ligament (PCL) reconstruction (PCLR).

Purpose: To sequentially evaluate tunnel enlargement and radiographic posterior laxity through double-bundle PCLR using autologous hamstring tendon grafts.

Study Design: Case series; Level of evidence, 4.

Methods: We prospectively analyzed 13 patients who underwent double-bundle PCLR for an isolated PCL injury. Three-dimensional computed tomography images were obtained at 3 weeks, 6 months, and 1 year postoperatively, and the tunnel enlargement was calculated by sequentially comparing the cross-sectional areas of the bone tunnels. We also sequentially measured radiographic posterior laxity. The correlation between the tunnel enlargement ratio and the postoperative increase in posterior laxity was evaluated.

Results: The cross-sectional area at the aperture in each tunnel significantly increased from 3 weeks to 6 months ($P < .003$), but it did not continue doing so thereafter. The 6-month tunnel enlargement ratios of the femoral anterolateral tunnel, the femoral posteromedial tunnel, the tibial anterolateral tunnel, and the tibial posteromedial tunnel were 31.6% ± 23.5%, 90.3% ± 54.7%, 30.5% ± 26.8%, and 49.6% ± 37.0%, respectively, while the corresponding ratios at 1 year were 28.1% ± 19.8%, 83.1% ± 56.9%, 26.8% ± 32.8%, and 47.6% ± 39.0%, respectively. The posterior laxity was 9.0 ± 4.0 mm, −1.5 ± 2.3 mm, 3.4 ± 2.0 mm, and 3.9 ± 1.9 mm, preoperatively, immediately after surgery, 6 months and 1 year postoperatively, respectively. From the immediate postoperative period, the posterior laxity significantly increased at 6 months postoperatively ($P < .001$), but it did not thereafter. The postoperative increase in posterior laxity had a significant positive correlation with the anterolateral tunnel enlargement ratio in both femoral and tibial tunnels at 6 months ($\rho = 0.571\text{-}0.699$; $P = .011\text{-}.041$) and 1 year ($\rho = 0.582\text{-}0.615$; $P = .033\text{-}.037$).

Conclusion: Tunnel enlargement after PCLR mainly occurred within 6 months, with no progression thereafter. The anterolateral tunnel enlargement positively correlated with postoperative increase in posterior laxity.

Keywords: tunnel enlargement; posterior cruciate ligament; reconstruction; posterior laxity; 3-dimensional computed tomography; cross-sectional area

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Tunnel enlargement after anterior cruciate ligament reconstruction (ACLR) using autologous hamstring tendon grafts is a well-known phenomenon with multiple etiological factors.[10] However, tunnel enlargement after posterior cruciate ligament (PCL) reconstruction (PCLR) has not been fully elucidated. Only 1 clinical study has been carried out, which reported that the total tunnel volume did not significantly change after single-bundle PCLR.[18] Moreover, no clinical study has investigated tunnel enlargement after double-bundle PCLR, which is biomechanically advantageous over single-bundle PCLR.[9,15] The clinical problems of tunnel enlargement are that enlarged tunnels frequently make it difficult to create proper tunnel placement or sometimes require a 2-staged procedure with bone grafting[33,34] (in the case of revision surgery). However, it is still unclear whether tunnel enlargement is correlated with postoperative posterior knee laxity.

Therefore, this study aimed to prospectively evaluate femoral/tibial tunnel enlargement after double-bundle PCLR with autologous hamstring tendon grafts using

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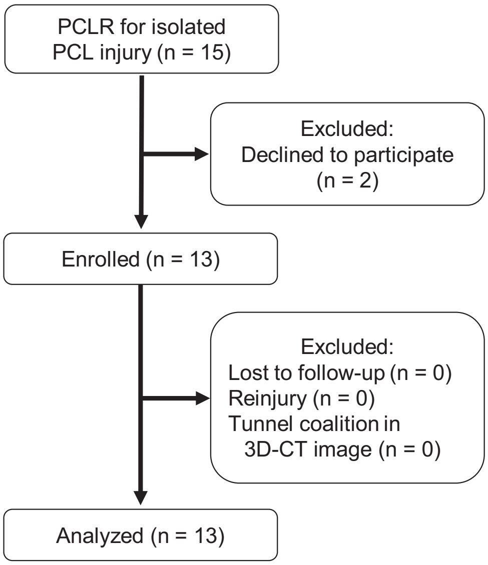

Figure 1. Flowchart of patient selection. 3-D CT, 3-dimensional computed tomography; PCL, posterior cruciate ligament; PCLR, posterior cruciate ligament reconstruction.

reliable 3-dimensional (3-D) multiplanar reconstructed computed tomography (CT) images[20] and accurate imaging modality for evaluating tunnel enlargement.[27] We hypothesized that significant tunnel enlargement would occur in both the femoral and tibial tunnels, especially at the tunnel aperture, and that tunnel enlargement would positively correlate with an increase in postoperative posterior laxity.

METHODS

This study was approved by our institutional review board. Patients who underwent double-bundle PCLR for unilateral isolated grade 2 or grade 3 PCL injury[12] between January 2017 and December 2018 were prospectively enrolled in this study. All patients had persistent posterior instability or pain during daily or sporting activities despite more than 3 months of conservative treatment in our institution or other clinics. After receiving preoperative informed consent forms, 13 patients agreed to participate in the study (12 men, 1 woman; mean age, 41 years; age range, 20-51 years at the time of surgery). None of the studied patients was excluded during the duration of follow-up (Figure 1).

TABLE 1
Patient Demographic Data (N = 13)[a]

Sex, M/F, n	12/1
Side, R/L, n	5/8
Age, y	41.0 ± 9.7 (22-51)
Time from injury to surgery, months	89.7 ± 139.5 (3-397)
Height, cm	169.8 ± 8.6 (150-187)
Weight, kg	72.3 ± 15.4 (47-118)
Treatment type, none/repair/resection, n	
Medial meniscus	9/1/3
Lateral meniscus	11/2/0
Chondral lesion,[b] grades 0/1/2/3/4, n	
Patella	9/2/2/0/0
Trochlea	10/0/1/0/2
MFC	5/4/4/1/2
LFC	8/5/0/0/1
MTP	3/4/6/0/0
LTP	5/4/3/1/0
Preoperative posterior laxity, mm	9.7 ± 3.4 (3.9-16.2)

[a] Data are reported as mean ± SD (range) unless otherwise indicated. F, female; L, left; LFC, lateral femoral condyle; LTP, lateral tibial plateau; M, male; MFC, medial femoral condyle; MTP, medial tibial plateau; R, right.

[b] Intraoperative arthroscopic findings.[30]

The cause of the trauma was related to sporting activities in 10 patients, work-related injuries in 2, and traffic accident in 1. The demographic data of the patients are shown in Table 1.

Surgical Technique

With the patient in the supine position, arthroscopic diagnosis was performed via standard anteromedial and anterolateral (AL) portals. For the femoral tunnel, we cleared the soft tissue, including the remnants of the torn PCL, using a mechanical shaver and visualized the anatomic landmarks for the PCL femoral footprint.[7] We then separately inserted two 2.4-mm k-wires into the center of the AL and posteromedial (PM) bundles of the PCL footprints using the inside-out manner at 100° to 110° of knee flexion. Subsequently, to match the diameters of the grafts, two 15- to 20-mm sockets were created by overdrilling via the k-wires, with a diameter of 6.0 to 8.0 mm for the AL tunnel and 5.0 to 6.0 mm for the PM tunnel. We cleared the remnants of the torn PCL again using a mechanical shaver via a PM portal to create the tibial tunnel and clearly visualized the anatomic landmarks for the PCL tibial footprint.[3]

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Ethical approval for this study was obtained from Osaka Rosai Hospital (No. 31-113).

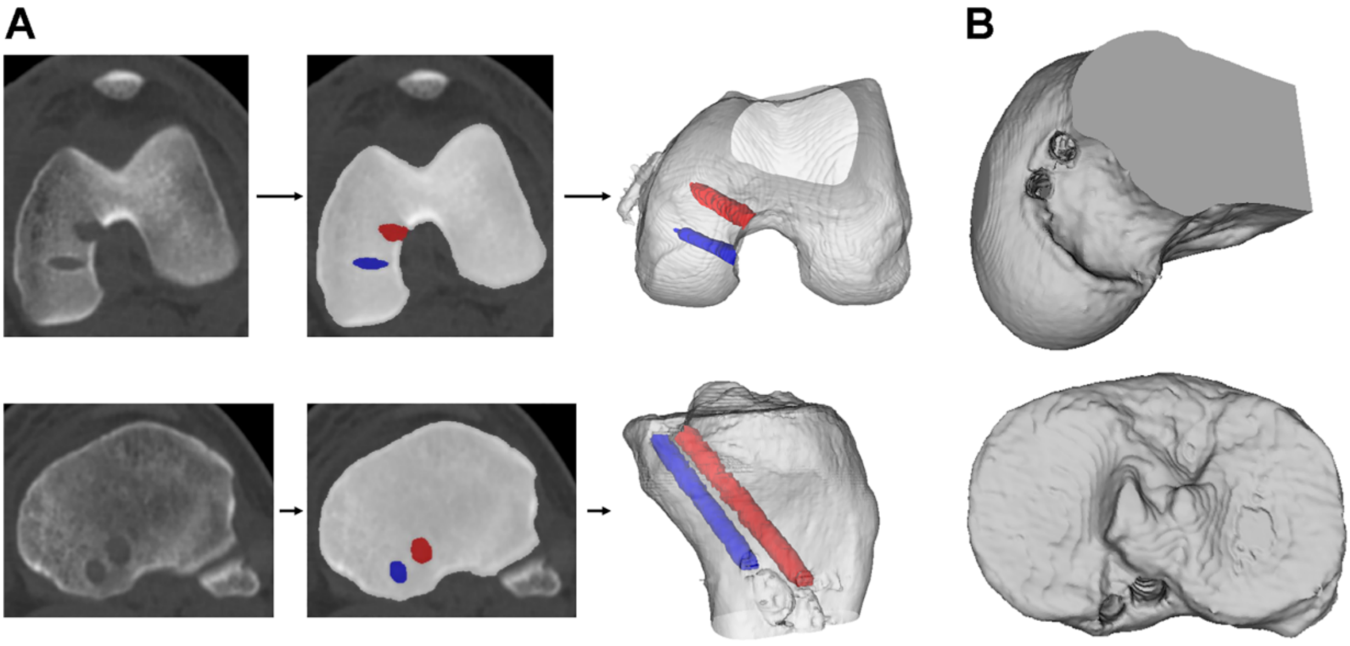

Figure 2. (A) Segmentation and reconstruction to the 3-D models from a CT image. The white, red, and blue 3-D models represent the femur/tibia, anterolateral tunnels, and posteromedial tunnels, respectively. (B) Tunnel apertures on the 3-D CT images. 3-D, 3-dimensional; CT, computed tomography.

Viewing via the PM portal, two 2.4-mm guide pins were inserted using the outside-in manner from the medial tibial cortex to the center of each bundle footprint with a tibial tip aimer (Smith & Nephew Endoscopy). After checking the location of the tips of the guide pins with frontal/lateral radiographs, the guide pins were then overdrilled with a 6.5- to 9.0-mm drill for the AL tunnel and a 5.5- to 7.0-mm drill for the PM tunnel, again matching the diameters of the grafts. The autogenous semitendinosus and gracilis tendons were harvested and made into tripled grafts of 80- to 85-mm in length. The semitendinosus tendon was used for the AL graft while the gracilis tendon was used for the PM graft. Both ends of the grafts were unified and sutured with 2 No. 2 polyethylene sutures. After the passage of the grafts, 2 Endobuttons (Smith & Nephew Endoscopy) were set on the cortex of the medial femoral condyle and unified with the sutures. Subsequently, the graft sutures for the tibial side were connected with 2 Double-Spike Plates (MEIRA), and the creep of the construct was removed through repetitive manual pulling. Finally, these grafts were fixed to the tibia under a total initial tension of 10 N (5 N for the AL graft and 5 N for the PM graft) at knee extension.

Postoperative Rehabilitation

The knees were postoperatively immobilized at the extension with braces for 3 weeks. Partial weightbearing was initiated at 3 weeks, and full weightbearing was permitted at 5 weeks. Range-of-motion (ROM) exercises were also started at 3 weeks and gradually increased, while the knee flexion angle was limited to 90° for 6 weeks, 120° for 3 months, and 135° for 6 months. Jogging and running were allowed at 4 and 6 months, respectively. Patients were allowed to return to their previous activity levels at 10 months.

CT Protocol

CT examinations were performed using a CT scanner (SOMATOM Sensation 64 or SOMATOM Definition; Siemens) at 3 weeks (just prior to initiating the ROM exercises), 6 months, and 1 year postoperatively. The volume areas were 10 cm above and below the joint line of the knee. The beam collimation was 19.2 mm, whereas the tube voltage current was 80 mA/120 kV, the acquisition matrix 512 × 512, the field of view 180 mm, the slice thickness 0.5 mm, and the CT dose index 7.21 mGy.

Cross-Sectional Area Measurement of Bone Tunnels

The Digital Imaging and Communications in Medicine data obtained from the CT scans were transferred to a personal computer (Dell Precision T1600; Dell). These data were reconstructed into 3-D constructs of the whole of the femoral/tibial model as well as the tunnel models at 3 weeks, 6 months, and 1 year using a program based on a modified version of the Visualization Tool Kit (Kitware)[24] (Figure 2A). We confirmed that all the tunnels were created within anatomic footprints and without any tunnel coalitions at any time points (Figure 2B).

The entire 3-D femoral/tibial models at 6 months and 1 year were superimposed onto those at 3 weeks using a

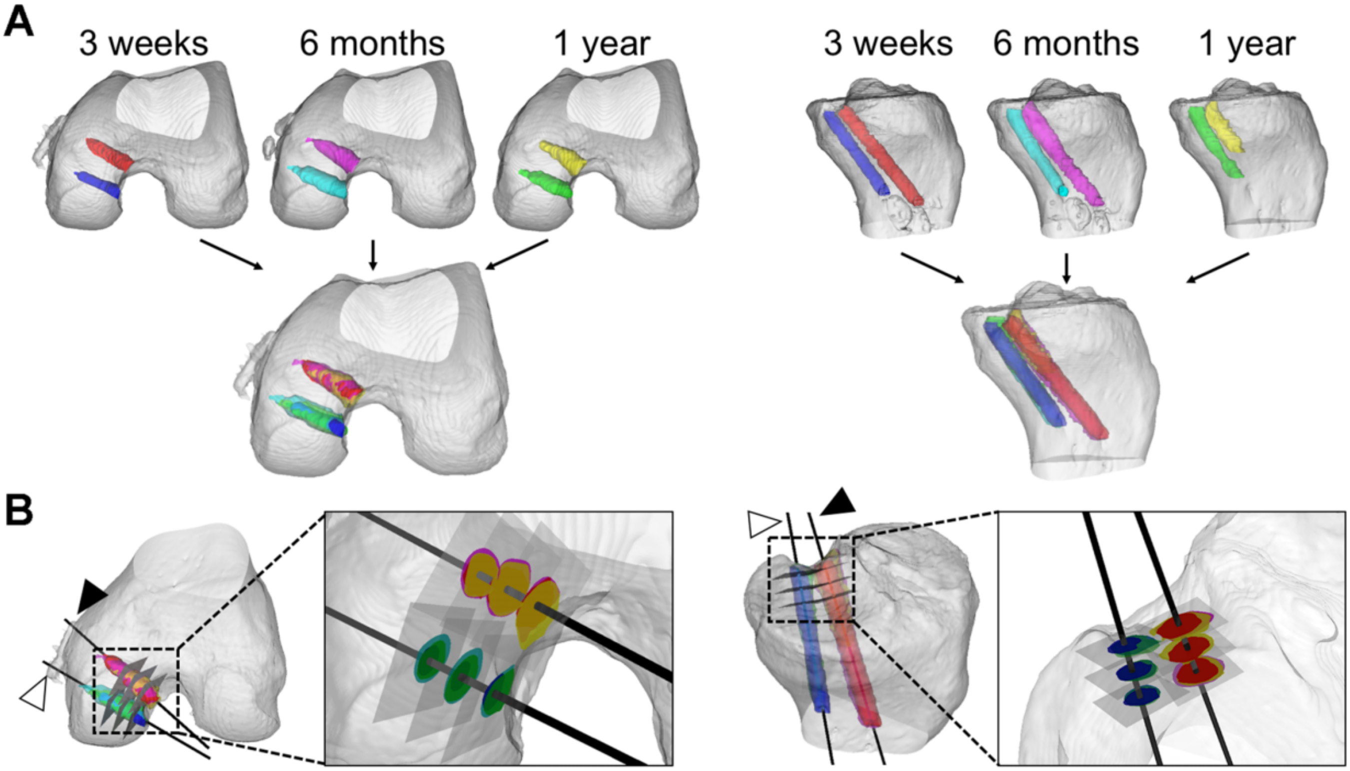

Figure 3. (A) Superimposition of the 3-dimensional (3-D) models of the tibia and femur and the bone tunnels at 3 weeks, 6 months, and 1 year postoperatively. The red, pink, and yellow 3-D models represent the femoral/tibial anterolateral tunnels at 3 weeks, 6 months, and 1 year, respectively. The blue, light blue, and green 3-D models represent the femoral/tibial posteromedial tunnels at 3 weeks, 6 months, and 1 year, respectively. (B) Measurement of the cross-sectional areas of the femoral/tibial tunnels at 3 weeks, 6 months, and 1 year postoperatively. The measurement was performed by cutting the 3-D models of the femoral/tibial tunnels along the planes perpendicular to the tunnel axes (white and black arrowheads), at the aperture, and 5 mm and 10 mm from the aperture.

surface registration technique, and the respective translational/rotational matrixes were obtained.[23,31,32] The 3-D femoral/tibial bone tunnel models at 6 months and 1 year were equally superimposed using these matrixes so that tunnel enlargement could be evaluated in the same 3-D coordinate system (Figure 3A). The axes of the femoral/tibial bone tunnels at 3 weeks after surgery were defined as the longitudinal axes of the principal axes of inertia (eigenvectors of the tensor of inertia). The centroids of the numerous triangular facets forming the surface of the 3-D femoral/tibial bone tunnel models were used for calculating the moment arm around the axis, and the principal axes of inertia were automatically determined.[23,31,32] Subsequently, the cross-sectional area (CSA) of the tunnel was calculated by cutting the 3-D femoral/tibial bone tunnel models along the planes perpendicular to the tunnel axis. The most distal plane completely surrounded by bony areas was defined as the femoral aperture site. Two additional planes were also created at 5 mm and 10 mm from the aperture site. For the tibia, the most proximal plane completely surrounded by bony areas was defined as the tibial aperture site, and 2 more planes were also created at 5 mm and 10 mm from the aperture site. The superimposed 3-D tunnel models at 6 months and 1 year postoperatively were also sectioned in the same planes (Figure 3b). The enlargement ratio of the tunnel was evaluated by comparing the CSA among the 3 time points; for instance, the enlargement ratio at 6 months was defined as the proportional increase of the CSA at 6 months in percentages with reference to the CSA at 3 weeks. We then compared the magnitude of the femoral AL, femoral PM, tibial AL, and tibial PM tunnel enlargement ratios at the apertures.

The intraobserver intraclass correlation coefficient (ICC) of the measurement of the CSA had been conducted in the previous study.[31] For the assessment of intraobserver reliability, a single orthopedic surgeon (Y. Tachibana) measured the 1-year postoperative CSA of each tunnel aperture in all the studied patients 3 times, with an interval of 14 days between measurements. The intraobserver ICC was 0.975. For the assessment of interobserver reliability, another independent orthopedic surgeon measured the 1-year postoperative CSA in each patient. The interobserver ICC was 0.874. For the calculation of both intra- and interobserver ICC, all the steps to measure the CSA were duplicated, superimposing the entire 3-D bone model at 1 year onto the one at 3 weeks with a surface registration technique and creating the planes to section the 3-D tunnel model at the aperture site.

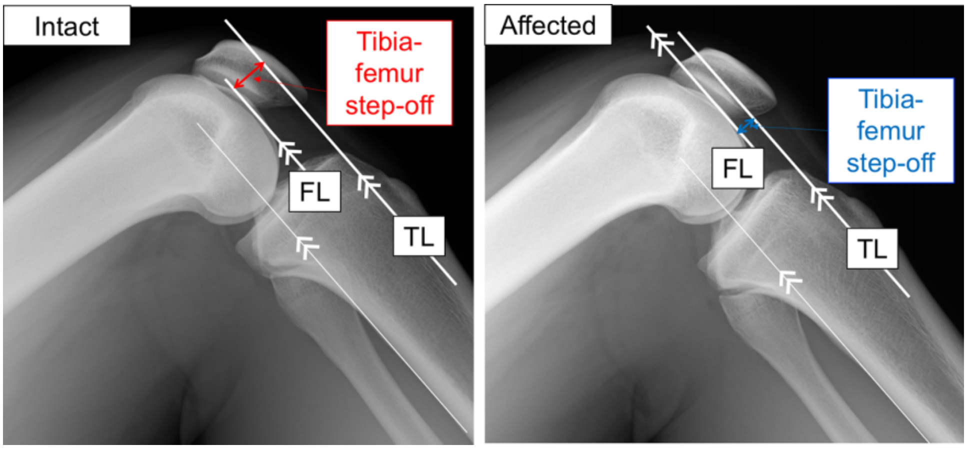

Figure 4. Evaluation of posterior laxity on the gravity sag view of lateral radiographs. The side-to-side difference of the tibia-femur step-off, the interval between TL and FL, was defined as the posterior laxity. FL, femoral line: parallel to the tibial axis and across the middle point between the distal borders of the lateral and medial condyles; TL, tibial line: parallel to the tibial axis and across the anterior border of the tibial third plateau.

Radiographic Posterior Laxity

With regard to the evaluation of posterior laxity, lateral radiographies with gravity sag views (GSV)[29] were performed preoperatively; immediately postoperatively; and 3 months, 6 months, and 1 year postoperatively. We routinely use this radiographic technique since it can be easily performed in daily clinical practice and can visualize the posterior tibial translation in the same position of the posterior sag sign under a posterior load by the gravity of the patient's shank weight. Patients were placed in a supine position along 1 long axis of the table with both hips flexed at 45° and both knees kept upright at 90° of flexion to capture the GSVs. First, the tibial axis was defined as a line parallel to the posterior cortex that had started passing through a point 15 cm from the joint line on the posterior cortex.[13] Second, the tibial line (TL) was defined as the line parallel to the tibial axis and across the anterior border of the tibial plateau, whereas the femoral line (FL) was defined as the line parallel to the tibial axis and across the middle point between the distal borders of the lateral and medial condyles. The radiographic posterior laxity was defined as the side-to-side difference of the tibial-femoral step-off: the interval between TL and FL (Figure 4). The posterior laxity was measured preoperatively, immediate postoperatively, and 6 months and 1 year postoperatively.

For assessment of intraobserver reliability, a single orthopedic surgeon (Y. Tachibana) measured the posterior laxity in each of the 13 patients 3 times, with an interval of 14 days among measurements. The examiner measured the posterior laxity using all the lateral plain radiographies at all the time points: preoperatively; immediately postoperatively; 6 months postoperatively; and 1 year postoperatively. The intraobserver ICC of the posterior laxity was 0.975. For the assessment of interobserver reliability, 2 other orthopedic surgeons (Y. Tanaka and K.K.) independently measured the posterior laxity in each lateral radiograph of the 13 patients at each time point. The interobserver ICC was 0.874. For the calculation of both intra- and interobserver ICC, the examiners repetitively measured the posterior laxity on the same images on separate occasions to decrease the patients' radiation exposure.

In addition, we evaluated the correlation between the postoperative increase in posterior laxity from the immediate postoperative period to 6 months and 1 year postoperatively and the tunnel enlargement ratios at the apertures at 6 months and 1 year postoperatively.

Statistical Analysis

The JMP software (JMP Pro Version 13.1.0; SAS Institute) was used for all statistical analyses. For the power analysis, the change (mm^2) in the mean CSA at the aperture of the 4 bone tunnels from 3 weeks to 6 months was chosen. The power analysis (power, 0.8; α, .05; detectable difference, 14.8; SD, 7.7) indicated a sample-size requirement of 5 patients for valid comparisons. The null hypothesis of normal distribution of the data obtained in this study (the mean CSA at the aperture of the 4 bone tunnels at 3 weeks) was tested and denied by the Shapiro-Wilk test ($P = .53$). Thus, the Wilcoxon signed-rank test was used to compare the CSAs among the 3 timepoints as well as the tunnel enlargement ratios among the 4 bone tunnels. A single linear regression analysis (Spearman rank correlation coefficient analysis) was used to examine the relationship between the postoperative change in posterior laxity and the tunnel enlargement ratio. $P < .05$ was considered statistically significant.

RESULTS

Posterior Laxity

The tibia in the PCL-deficient knee was located posteriorly by 9.0 ± 4.0 mm in comparison with that in the contralateral healthy knee. Immediately after PCLR, the tibia was anteriorly reduced with significance ($P < .001$). However, the tibia exhibited a significant increase in posterior laxity up to 6 months postoperatively ($P < .001$); however, no further significant change occurred from 6 months to 1 year.

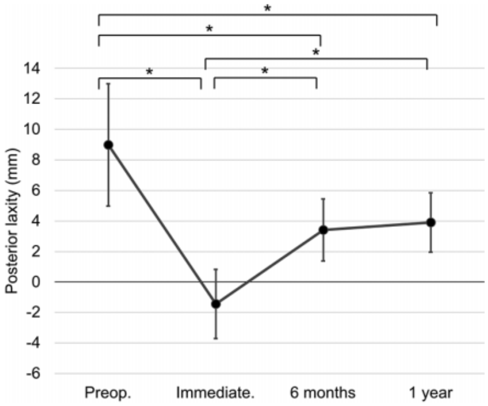

Figure 5. Sequential change of posterior laxity before and after posterior cruciate ligament reconstruction. A positive value signifies that the tibia in the affected knee was posteriorly displaced in comparison with that in the contralateral healthy knee. *$P < .05$. Immediate, immediately postoperatively; Preop, preoperatively.

The postoperative posterior laxity was −1.5 ± 2.3 mm, 3.4 ± 2.0 mm, and 3.9 ± 1.9 mm, immediately after surgery, at 6 months and at 1 year, respectively. Compared with the preoperative posterior laxity, the postoperative values were significantly improved at all timepoints (Figure 5). The postoperative increase in posterior laxity from the immediate postoperative timepoint was 4.9 ± 1.5 mm up to 6 months and 5.3 ± 1.7 mm up to 1 year.

CSA and Tunnel Enlargement Ratio

The CSA in each tunnel significantly increased from 3 weeks to 6 months at the tunnel aperture ($P < .003$); however, it did not significantly change from 6 months to 1 year (Figure 6). At the aperture, 6-month tunnel enlargement ratios of the femoral anterolateral tunnel, the femoral posteromedial tunnel, the tibial anterolateral tunnel, and the tibial posteromedial tunnel were 31.6% ± 23.5%, 90.3% ± 54.7%, 30.5% ± 26.8%, and 49.6% ± 37.0%, respectively, while the corresponding ratios at 1 year were 28.1% ± 19.8%, 83.1% ± 56.9%, 26.8% ± 32.8%, and 47.6% ± 39.0%, respectively.

The tunnel enlargement ratio of the PM tunnels was larger than the corresponding ratio of the AL tunnels (Figure 7). Conversely, at 10 mm inside the aperture, the CSAs at 1 year postoperatively were significantly smaller than those at 6 months ($P < .05$), except for the tibial PM tunnel (Figure 6).

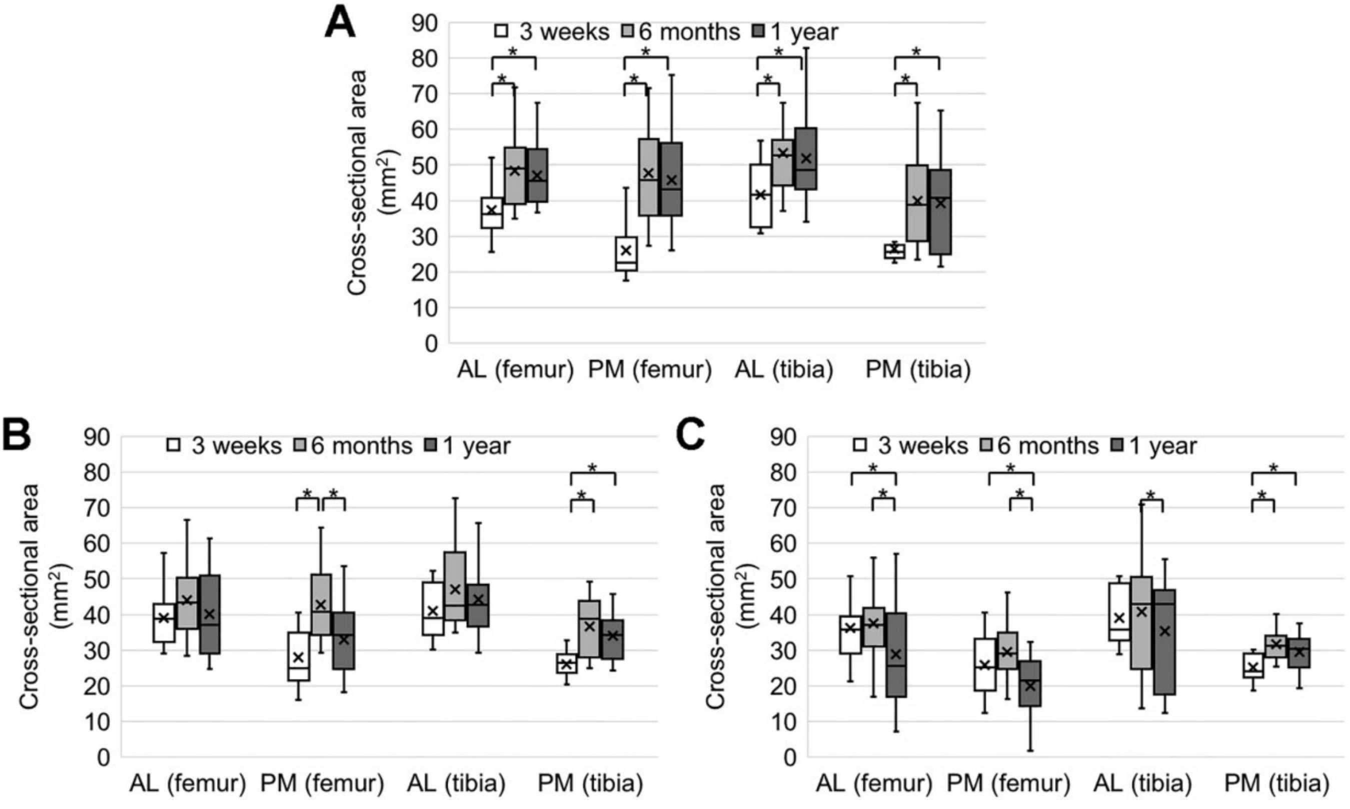

Figure 6. Box plots of the change in the cross-sectional area of the bone tunnels over time: (A) at the aperture; (B) 5 mm from the aperture; and (C) 10 mm from the aperture. The X represents the mean value. *$P < .05$. AL, anterolateral tunnel; PM, posteromedial tunnel.

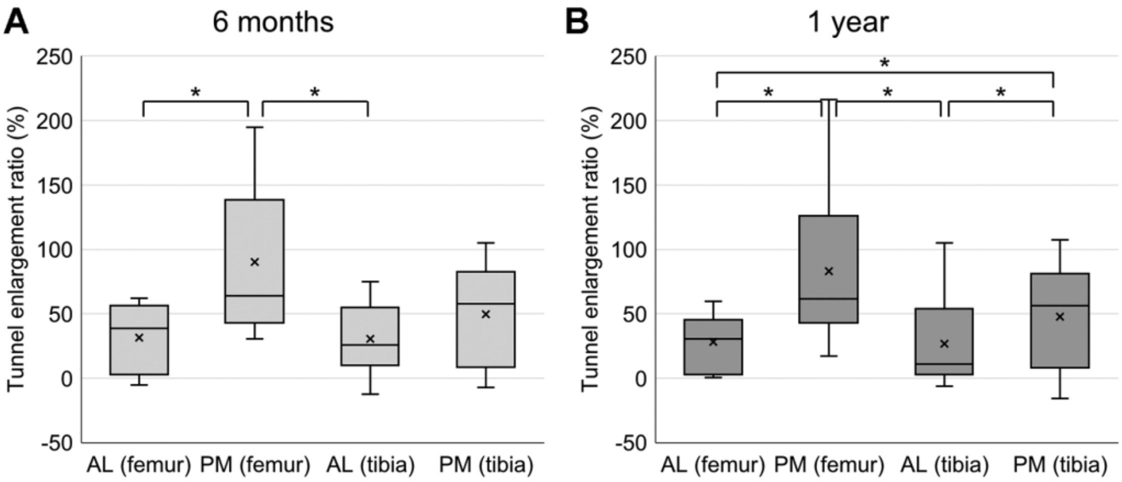

Figure 7. Box plots comparing the tunnel enlargement ratios among the bone tunnels at 6 months and 1 year postoperatively. The X represents the mean value. *$P < .05$. AL, anterolateral tunnel; PM, posteromedial tunnel.

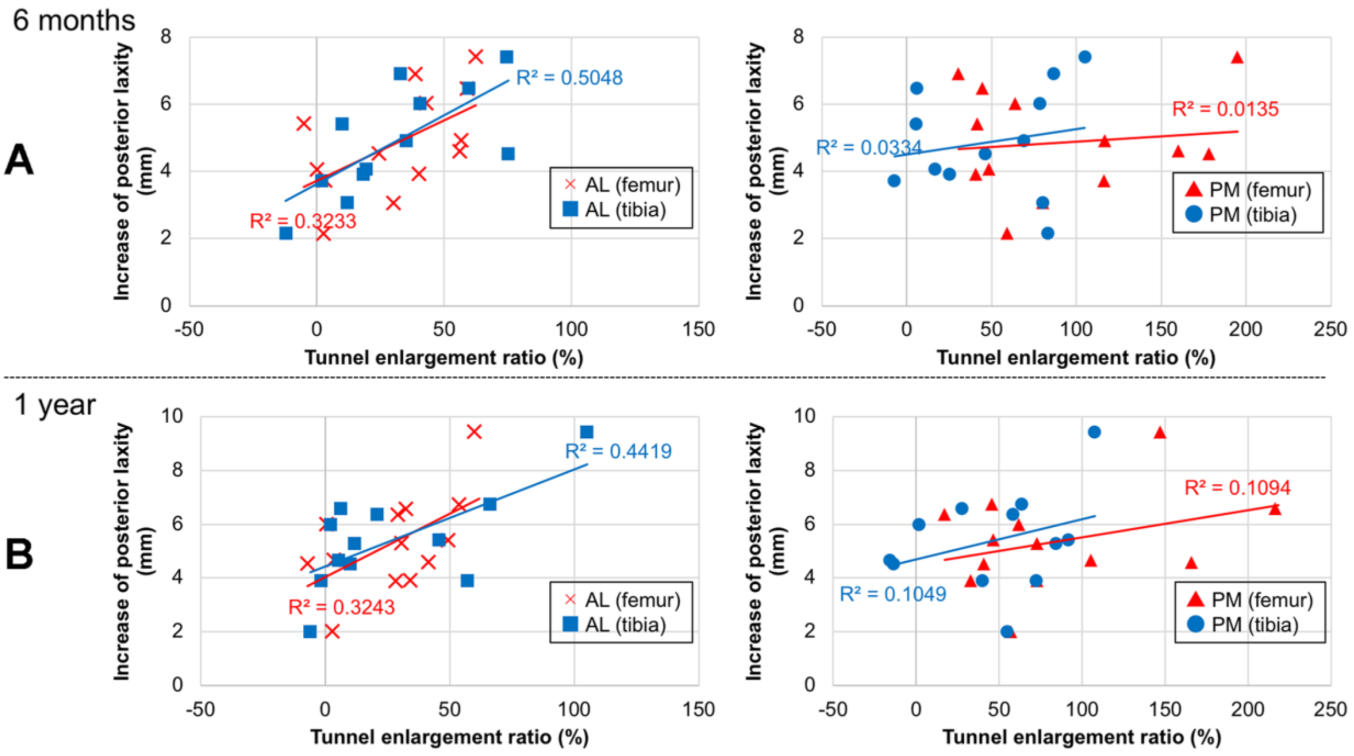

Figure 8. Scatterplot of the tunnel enlargement ratio at the aperture and postoperative increase in posterior laxity at (A) 6 months and (B) 1 year postoperatively. *$P < .05$. AL, anterolateral; PM, posteromedial.

Correlation Between Tunnel Enlargement and Postoperative Increase in Posterior Laxity

There was a significant positive correlation between the postoperative increase in posterior laxity and the femoral AL tunnel enlargement ratio at 6 months ($\rho = 0.571$; $P = .041$) and 1 year ($\rho = 0.582$; $P = .037$), and the tibial AL tunnel enlargement ratio at 6 months ($\rho = 0.699$; $P = .011$) and 1 year ($\rho = 0.615$; $P = .033$) (Figure 8). Conversely, no significant correlation was observed between the postoperative increase in posterior laxity and the femoral or tibial PM enlargement ratio.

Clinical Findings at Final Follow-up

None of the patients had knee swelling, residual subjective posterior instability, loss of extension exceeding 5°, or

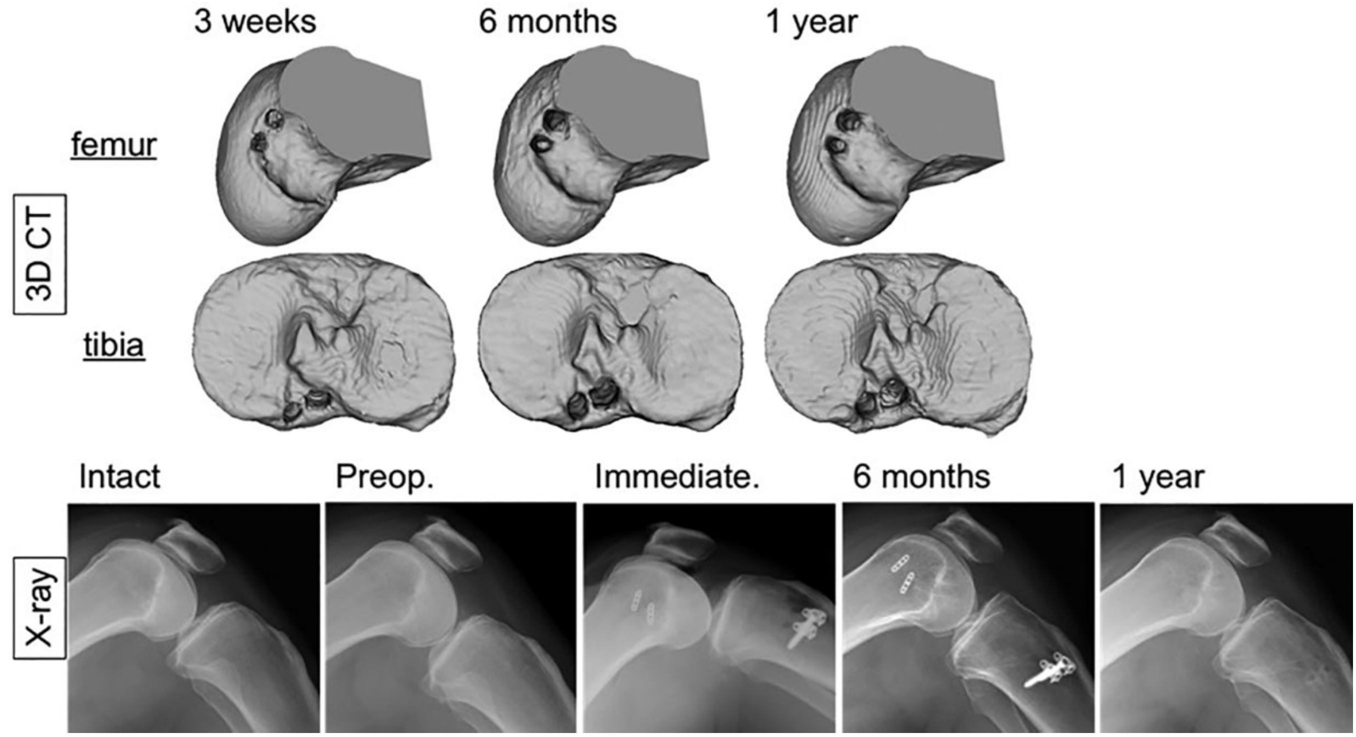

Figure 9. Sequential change of the tunnel apertures on 3-dimensional computed tomography images and the radiographic posterior laxity through the double-bundle PCLR in an illustrative case. Immediate, immediately postoperatively; PCLR, posterior cruciate ligament reconstruction; Preop, preoperatively.

flexion exceeding 10° at 1 year. All patients had improved from grade 2 or grade 3 preoperatively to grade 1 in the posterior drawer test at the final follow-up. The sequential change of the tunnel apertures in the 3-D CT images and plain radiographs before and after the double-bundle PCLR are shown in a representative case (Figure 9).

DISCUSSION

The four most important findings of the present study were as follows: (1) a significant tunnel enlargement at the aperture occurred at 6 months after PCLR in both femoral/tibial tunnels but did not significantly change thereafter up to 1 year; (2) the tunnel enlargement ratio was largest at the aperture while it was small inside the tunnel; (3) the PM tunnel enlargement was larger than the AL tunnel enlargement in both femoral/tibial tunnels; and (4) the AL tunnel enlargement in both tunnels had a positive correlation with the postoperative increase in posterior laxity.

The current study is the first to sequentially evaluate the CSAs of bone tunnels after PCLR using 3-D CT images; the tunnel enlargement in both the femoral and the tibial tunnels occurs mainly at 6 months postoperatively but does not change significantly thereafter. This result corroborates the findings of previous studies focusing on ACLR, which revealed that tunnel enlargement occurred during the first 3 to 6 months and did not continue afterward.[17,28,36] Potential factors of tunnel enlargement after ACLR can be divided into 2 categories: mechanical factors, such as graft-tunnel motion,[10,14] nonanatomic tunnel placement,[38] and aggressive rehabilitation[35]; and biological factors, such as the nonspecific inflammatory response mediated by synovial fluid within the bone tunnel[5] and the immune response to allografts.[27] The transplanted PCL graft is susceptible to mechanical stress during postoperative rehabilitation, including the effects of the gravity of the patient's shank weight,[29,39] knee flexion, or hamstring contraction.[11,22] Moreover, there will likely be high mechanical stress between the PCL graft and the tunnel wall at the tunnel aperture such as killer turn for the tibia[6,19,21] and the critical bending angle for the femur.[8,16] These mechanical factors cause significant tunnel enlargement at the aperture in each tunnel in the early postoperative term.

The current study demonstrated that the tunnel enlargement ratio was largest at the aperture but that it gradually decreased from the aperture toward the inside of the tunnel. The hamstring tendon graft is typically fixed extracortically using suspensory fixation devices. The graft moves longitudinally or transversely during postoperative rehabilitation around the extracortical fixation point as a fulcrum, which would increase with the distance from the extracortical fixation point and could lead to a larger tunnel enlargement ratio at the aperture than inside the tunnel.[4,23,31]

The tunnel enlargement ratio of the PM tunnel in both tunnels was larger compared with that of the AL tunnel.

Ahmad et al[2] examined the PCL bundle length by calculating the distance between the bundle attachments on the femur and tibia at each flexion angle and reported that the length change from 0° to 120° of knee flexion was less in the PM bundle than in the AL bundle. However, when choosing graft material, that with a larger CSA is generally used for the AL graft, whereas that with a smaller CSA is used for the PM graft (eg, semitendinosus tendon for the AL graft and gracilis tendon for the PM graft) because the AL bundle covers a larger area and has a higher stiffness than the PM bundle.[25,26] In addition, using a robotic system, Harner et al[9] revealed that the in situ force of the PM graft was higher than the corresponding force of the AL graft under a posterior tibial load. Consequently, the higher mechanical stress per unit area might be loaded more on the PM tunnel wall than on the AL tunnel wall, leading to a larger tunnel enlargement ratio.

The radiographic posterior laxity was -1.5 ± 2.3 mm in the immediate postoperative period, indicating that the double-bundle PCLR could successfully reduce the tibia under a posterior drawer due to the gravity of the patient's tibia.[9,15,37] However, the posterior laxity had postoperatively increased at 6 months, with a final value of 3.9 ± 1.9 mm at 1 year, which exhibited no significant change from that at 6 months. Thus, the posterior laxity recurred in the early postoperative period within 6 months but did not worsen thereafter. Furthermore, the AL tunnel enlargement ratio in both tunnels was positively correlated with the postoperative increase in posterior laxity at 6 months and at 1 year. Previous studies after ACLR reported that no significant correlation was observed between the tunnel enlargement and the instrumental anterior laxity.[28,32] Since there has still been little information on the tunnel enlargement after PCLR, further studies would be warranted to investigate the correlation between tunnel enlargement and the postoperative increase in posterior laxity, using other methodologies including a stress radiograph with a Telos device (Telos)[1,40] or with a kneeling technique.[13]

This study had a number of limitations. First, the sample size was small. Second, we did not evaluate clinical outcome scores such as Lysholm scores or Western Ontario and McMaster Universities Osteoarthritis Index scores. Third, only single linear regression analysis was performed for the correlation between the tunnel enlargement ratio and postoperative increase in posterior laxity, even though both these variables can be affected by multiple factors. Fourth, the duration of postoperative follow-up was only 1 year. However, we expected that further tunnel enlargement would not occur beyond 1 year after PCLR since several studies have demonstrated that the major part of tunnel enlargement occurs during the first 3 to 6 months but does not proceed thereafter following ACLR.[17,28,36] Fifth, the stress onto the PCL graft in the GSV might be affected by the individual patients' shank weight and might be smaller than that in the stress radiograph using a Telos device. However, the GSV is advantageous because the radiographic posterior laxity immediately after PCLR can be evaluated without any special stress device. Finally, the initial CT examination was not performed immediately postoperatively but at 3 weeks, although the mechanical stress onto the grafts/tunnel walls would be little during this 3-week postoperative period because the knees were immobilized with braces at the extension.

CONCLUSION

Tunnel enlargement after PCLR mainly occurred within 6 months, with no progression thereafter. The AL tunnel enlargement positively correlated with the postoperative increase in posterior laxity.

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