Original Article

Increased Bone Plug Depth From the Joint Increases Tunnel Enlargement in Anterior Cruciate Ligament Reconstruction Using Bone—Patellar Tendon—Bone Autograft With Suspensory Femoral Fixation

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Purpose: To determine a safe bone plug depth fixation zone based on early tunnel enlargement rates in anterior cruciate ligament (ACL) reconstruction using bone—patellar tendon—bone (BPTB) autograft with suspensory femoral fixation. **Methods:** Patients who had undergone rectangular tunnel ACL reconstruction using BPTB autograft with suspensory femoral fixation were retrospectively identified. Femoral and tibial tunnel aperture areas were measured on computed tomography 2 weeks and 6 months after surgery to calculate rates of femoral and tibial tunnel enlargement (FTE and TTE), respectively. Femoral bone plug depth (FBPD) and tibial bone plug depth (TBPD) were defined as the distance of the tip of the plug from the respective joint lines. Optimal FBPD and TBPD cutoff values were calculated for the following rates of FTE and TTE, respectively: 0%, 15%, 30%, and 50%. **Results:** Sixty-four patients (19 females, 45 males; mean age, 29.5 ± 12.3 years) were included in the study. The femoral and tibial tunnel apertures significantly enlarged over time. FBPD ($P < .001$; $r = 0.607$) and TBPD ($P = .013$; $r = 0.308$) were positively correlated with FTE and TTE, respectively. The optimal FBPD cutoff value was 2.8 mm for FTE rates of 0% and 15%, 3.6 mm for 30%, and 6.0 mm for 50%. The optimal TBPD cutoff value was 1.48 mm for a 0% TTE rate and 5.1 mm for those higher. The cutoff value specificities were lower for the tibial tunnel than the femoral tunnel for each tunnel enlargement rate. **Conclusion:** Early tunnel enlargement and bone plug depth were significantly correlated in bone the femoral and tibial tunnels. The degree of correlation was higher in the femoral tunnel. To minimize bone tunnel enlargement, the distal end of the femoral bone plug should be placed less than 2.8 mm from the tunnel aperture. **Level of Evidence:** Level IV, therapeutic case series

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Introduction

Although bone tunnel enlargement after anterior cruciate ligament (ACL) reconstruction using bone—patellar tendon—bone (BPTB) autograft is common,[1] its effect on postoperative clinical outcomes remains unclear.[2-9] Theoretically, tunnel enlargement can allow graft migration owing to delayed graft healing within the tunnel, which can lead to graft failure and recurrent instability.[8,10] Järvelä et al. reported a correlation between tunnel enlargement and anterior knee laxity.[11] Furthermore, revision surgery in patients with severe tunnel enlargement can be challenging because the enlargement interferes with creation of a new bone tunnel in the correct position; in some cases, an additional procedure, such as autologous bone graft harvesting, is required at the time of revision.[12]

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Therefore, bone tunnel enlargement should be minimized as much as possible.[8,13-17]

Tunnel enlargement has been associated with by several factors, including tunnel location,[18,19] type of fixation device,[8,12,16] biologic factors such as synovial fluid leakage into the tunnel and cell necrosis from drilling,[20,21] low-grade infection,[22] accelerated rehabilitation,[7,23,24] and bone plug position within the tunnel.[1,3,4,9] Among these, bone plug position is a variable, which can be adjusted during the operation. Tunnel enlargement is likely to occur at the graft—tunnel interface because of “wind shield-wiper motion,” especially when the bone plug is fixed deeply within the tunnel.

Femoral tunnel enlargement (FTE) occurs when the femoral bone plug is fixed deeply.[3,4] Although some studies have found a positive correlation between the deep tibial bone plug position tibial tunnel aperture enlargement,[3,25] others have not.[4,10] Uchida et al. reported a definite correlation between femoral bone plug depth (FBPD) and femoral tunnel aperture enlargement and that the femoral tunnel aperture was more susceptible to enlargement than the tibial one.[4] They concluded that the tendon—bone junction (TBJ) of the graft should be placed precisely at the femoral tunnel aperture. However, the position of the femoral bone plug may be difficult to ascertain during surgery and the position is often determined by the length of the patellar tendon graft; therefore, fixation positions may vary slightly. To prevent the protrusion of the femoral bone plug into the joint, additional traction into the tunnel is frequently performed. However, the allowable depth of the bone plug remains unclear.

The purpose of this study was to determine a safe bone plug depth fixation zone based on early tunnel enlargement rates in ACL reconstruction using BPTB autograft with suspensory femoral fixation. We hypothesized that tunnel enlargement correlated with bone plug depth in both the femoral and tibial tunnels.

Material and Methods

Protocol Approval

Institutional review board approval for the study was provided by Zenshukai Hospital (approval no. 22040601). Informed consent has been obtained by all study objects.

Study Design

Patients who underwent ACL reconstruction using a BPTB graft in our institution between March 2018 and February 2021 were retrospectively reviewed. Exclusion criteria were as follows: revision surgery, bilateral ACL reconstruction, grade III/IV articular cartilage damage, concomitant injury to other knee ligaments that required repair or reconstruction, loss to follow-up, and unavailable clinical or radiographic examination data.

Surgical Procedure

Anatomic rectangular tunnel ACL reconstruction using BPTB autograft with suspensory femoral fixation was performed by 7 surgeons. Briefly, the graft comprised a 10 mm-wide segment of patellar tendon attached to rectangular tibial and patellar bone plugs (5.5 × 10 × 15 mm) on each end. ULTRATAPE (Smith & Nephew Endoscopy, Andover, MA) was attached to each plug. Bony landmarks of the ACL footprint, such as the lateral intercondylar ridge, were arthroscopically confirmed,[26,27] and 2 round tunnels were created in parallel within both the femoral and tibial footprints using the outside-in technique (Fig 1, A and B). The 2 round holes were dilated into a rectangular tunnel using dilators (Smith & Nephew Endoscopy). A suspensory device (suture button; Arthrex, FL) was used for femoral fixation and the Double Spike Plate (Meira, Nagoya, Japan) was used for the tibial procedure. Both plugs were confirmed to be within their tunnel without protruding into the joint before final fixation. Using a pen marking, the middle of the tendinous portion of the graft was positioned almost at the middle position of the joint (Fig 1C). The limb position was fixed at 20° knee flexion without posterior drawer force and grafting was performed using a force of 20 N during fixation.[28] Force was measured using the Ligament tensioner 3 (Meira).

Postoperative Treatment

After surgery, range-of-motion exercises were initiated on day 2. In patients who did not undergo meniscus repair, partial and full weight-bearing were allowed at 1 and 3 weeks, respectively. If meniscus repair were performed, partial and full weight-bearing were allowed at 2 and 4 weeks, respectively. Return to sports was generally permitted 8 months after surgery. Muscle strength recovery and movement stability were examined during outpatient follow-up.

Imaging Evaluation

Computed tomography (CT) was performed on the surgical knee approximately 2 weeks and 6 months after surgery,[6,29-31] using a helical high-speed scanner (SCENRIA; Hitachi Medical Systems, Tokyo, Japan) with the following parameters: collimation, 16 × 0.625 mm; 175 mA; 120 kV; acquisition matrix, 512 × 512; field of view, 140 mm, and slice thickness, 0.5 mm. The VOX BASE software package (J-MAC, Tokyo, Japan) was used to evaluate the images and obtain cross-sectional data.

FBPD was defined as the distance from the femoral tunnel aperture to the tip of the bone plug and was measured graphically parallel to the tunnel from the aperture on the axial CT view. Similarly, the tibial bone

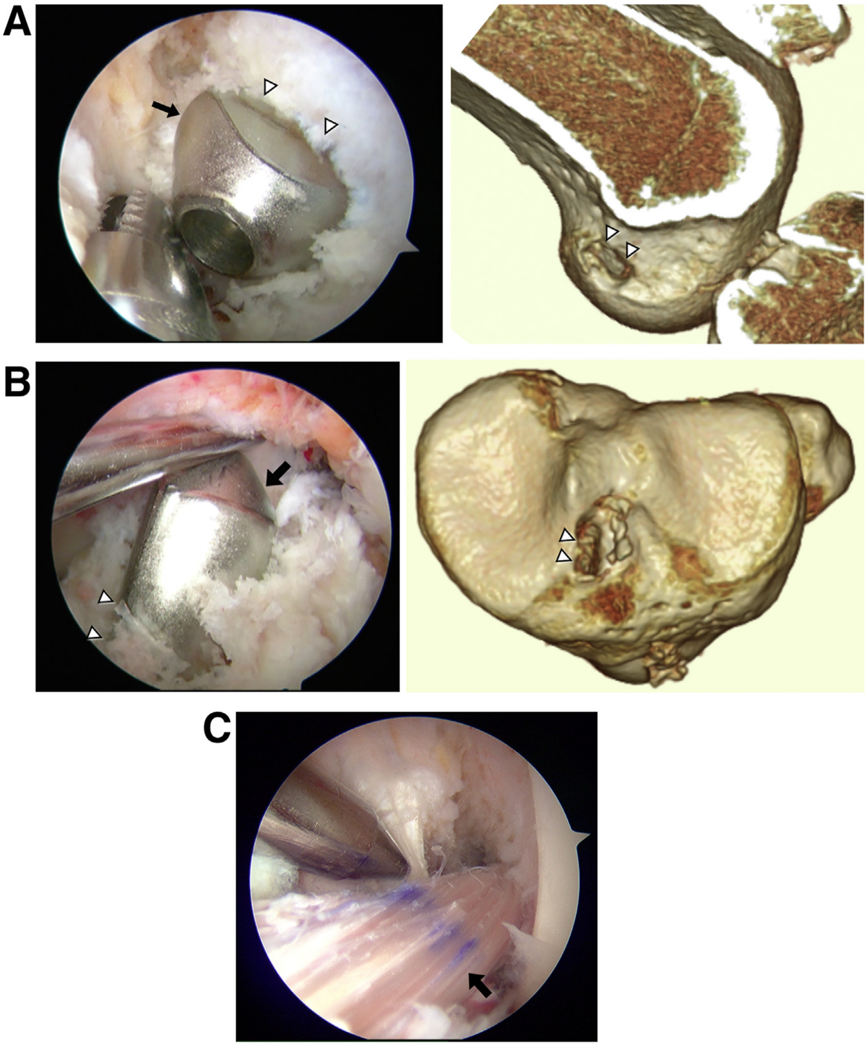

Fig 1. Intraoperative arthroscopic and postoperative three-dimensional computed-tomography (3D CT) images of the left knee. (A) Rectangular femoral tunnel creation with the dilator (black arrow), as viewed from the anterolateral portal. The white arrowheads in the arthroscopic and 3D CT images correspond to each other and indicate the rectangular femoral tunnel aperture. (B) Rectangular tibial tunnel creation with the dilator (black arrow) viewed from the anterolateral portal. The white arrowheads in the arthroscopic and 3D CT images correspond to each other and indicate the rectangular tibial tunnel aperture. (C) An arthroscopic view from the anterolateral portal after graft insertion confirmed the femoral bone plug was completely within the tunnel. The black arrow indicates the middle of the tendinous portion of the graft, which was marked in blue during the operation.

plug depth (TBPD) was defined as the distance from the tibial tunnel aperture to the tip of the bone plug and measured parallel to the tibial tunnel on the sagittal CT view (Fig 2, A and B). FBPD and TBPD were measured only at 2 weeks because the edge of the bone plug could not be accurately measured at 6 months, owing to bone union and absorption. Femoral and tibial tunnel aperture areas were measured on the reconstructed CT images obtained 2 weeks and 6 months after surgery using the method described by Yanagisawa et al.[29] (Fig 2, C and D). FTE and tibial tunnel enlargement (TTE) rates were calculated as follows: tunnel aperture area 6 months after surgery/tunnel aperture area 2 weeks after surgery × 100. Femoral and tibial tunnel location were evaluated using the quadrant method on three-dimensional (3D) CT (Fig 3, A and B). Tunnel angles were measured on postoperative plain anteroposterior and lateral radiography[32] (Fig 3, C and D). The safe zone was estimated by calculating the optimal cutoff value of bone plug depth cut-off values at several different angles, according to the tunnel enlargement rates. Measurements were performed independently by 2 orthopedic surgeons (S.K. and R.T.), who were blinded to the other's measurements, as well as their own previous ones. Both are licensed orthopedic surgeons in Japan and have expertise with image analysis and interpretation.

Clinical Evaluation

Patients were clinically examined before surgery and 1 year after to determine knee anterior stability and Tegner activity,[33,34] Lysholm,[33,34] and International Knee Documentation Committee (IKDC)[35,36] scores. Anterior knee instability was assessed using side-to-side difference, as measured on lateral stress radiography performed using a Telos device. The hospital office was responsible for coordinating the patient assessment process and ensuring data completeness. The specific

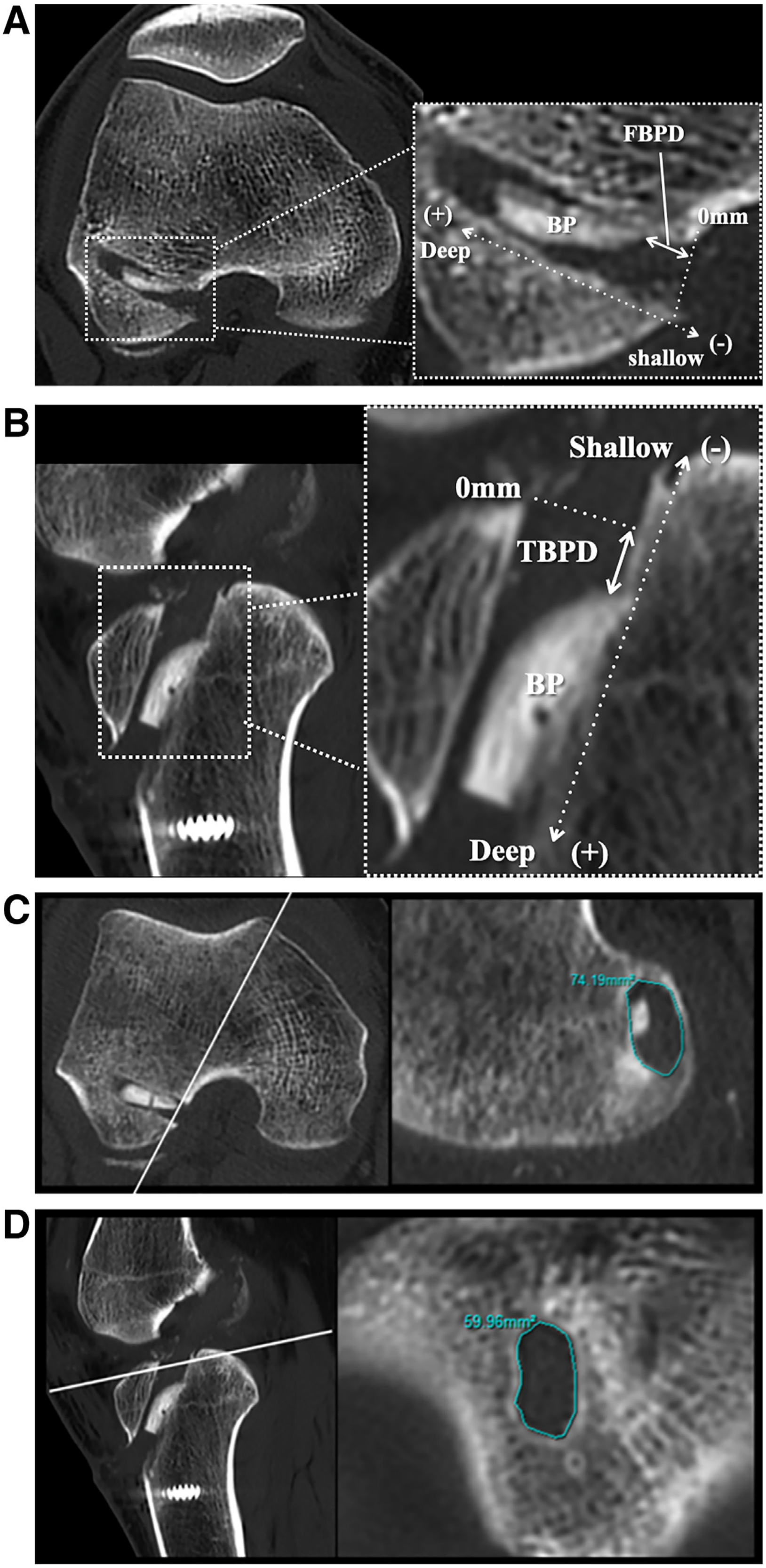

Fig 2. Measurements of femoral and tibial bone plug depth, bone plug length, and tunnel area on computed tomography of the right knee. (A) Femoral bone plug depth (FBPD) was defined as the distance from the distal end of the femoral bone plug (BP) to the tunnel aperture. (B) Tibial bone plug depth (TBPD) was defined as the distance from the proximal end of the tibial bone plug (BP) to the tunnel aperture. (C) Sagittal reconstruction was performed at a level parallel to the outer rim of the lateral femoral condyle. The contour of the femoral tunnel wall was traced on the slice 2 mm deep to the aperture to measure its cross-sectional area. (D) Axial reconstruction was performed at a level parallel to the outer rim of the intercondylar fossa of the tibia. The contour of the tibial tunnel wall was traced on the slice 2 mm deep to the aperture to measure its cross-sectional area.

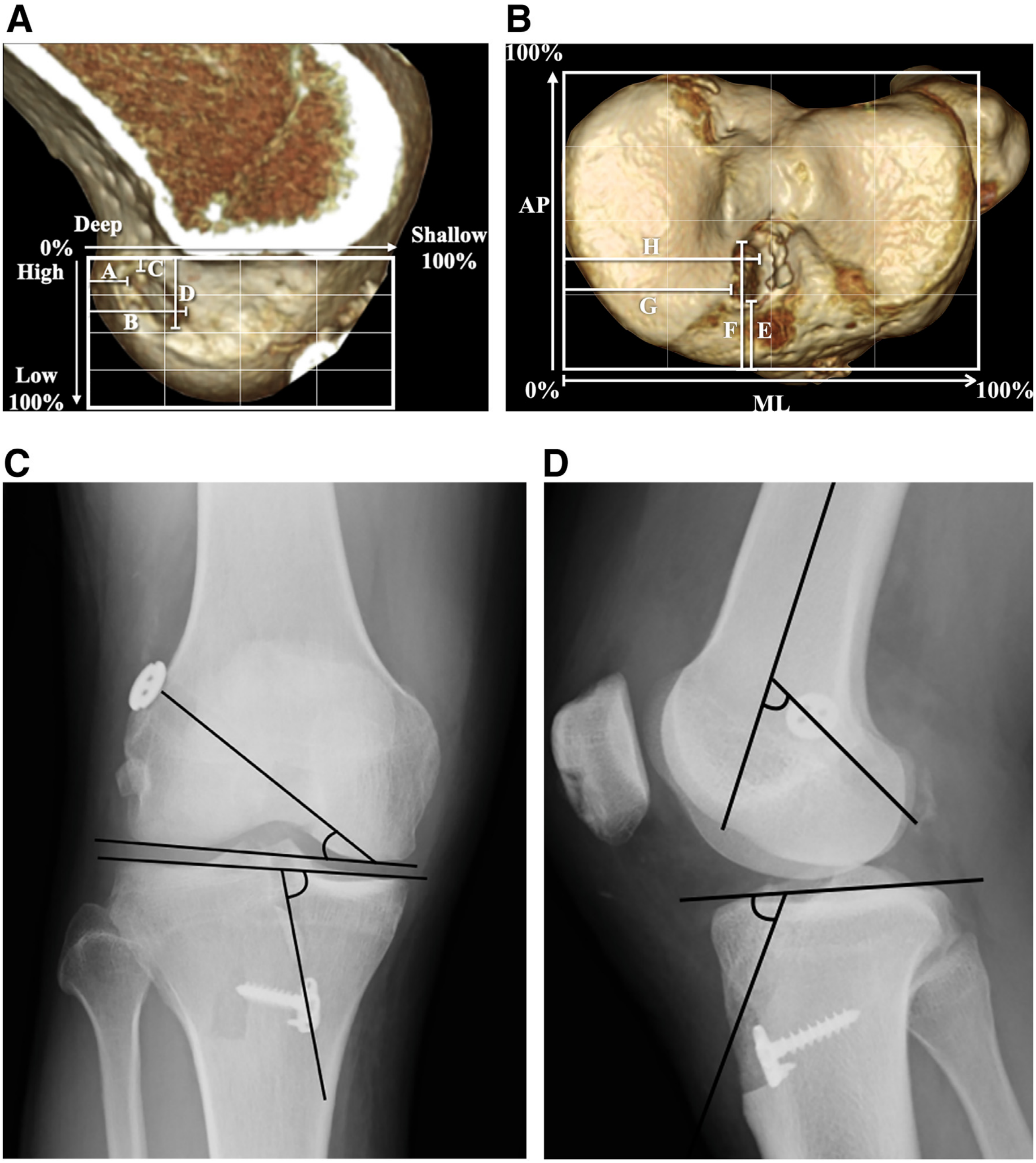

Fig 3. Measurement of tunnel location on three-dimensional computed-tomography and tunnel angles on plain radiography of the right knee. (A) Locations of the deep and shallow wall of the femoral tunnel were defined as the percentages of the distance from the most deep and shallow contour in reference to the total length of the lateral condyle parallel to the Blumensaat's (A and B). Similarly, locations of the high and low wall of the femoral tunnel were defined as the percentages of the distance from the intercondylar roof, with respect to the total depth of the intercondylar notch perpendicular to the Blumensaat's line (C and D). (B) Locations of the anterior and posterior wall of the tibial tunnel were defined as the percentages of the distance from the most anterior and posterior contour with respect to the anteroposterior (AP) length of the tibial plateau (E and F). Similarly, locations of the medial and lateral wall of the tibial tunnel were defined as the percentage of the distance from the most medial and lateral contour with respect to the mediolateral (ML) width of the tibial plateau (G and H). (C) The femoral and tibial tunnel angles were defined on anteroposterior radiography as the angle between the respective tunnel axes and joint surfaces. (D) The femoral tunnel angle on lateral radiography was defined as the angle between the femoral tunnel axis and the femoral shaft axis. The tibial tunnel angle on lateral radiography was defined as the angle between the tibial tunnel axis and the tibial joint surface.

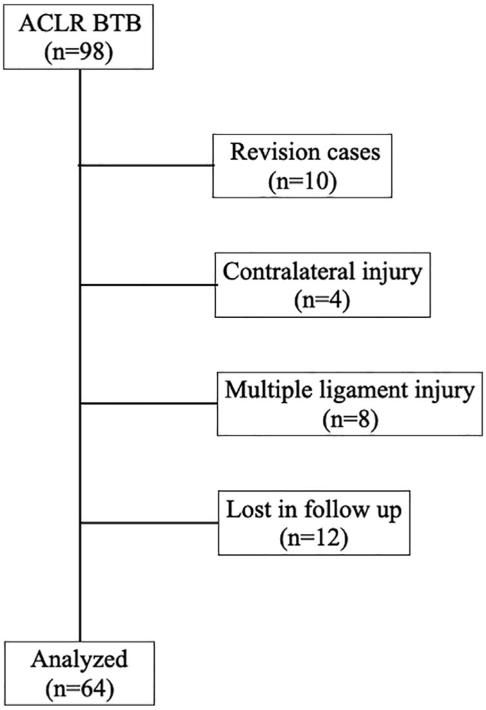

Fig 4. Study flowchart.

individuals who performed the assessments are not known. We also evaluated the minimal clinically important difference (MCID) and patient-acceptable symptomatic state (PASS) for each clinical score. According to a previous study, the MCIDs for Tegner activity, Lysholm, and IKDC scores were 1, 16.7, and 8.9, respectively; although the PASSes for Tegner activity and Lysholm scores were not reported, that for IKDC score was 75.9%.[37] We evaluated the number and percentage of patients who met these MCID and PASS criteria.

Statistical Analysis

Statistical analyses were performed using EZR software (Saitama Medical Center, Jichi Medical University, Saitama, Japan),[38] a graphical user interface for R (www.r-project.org). The paired *t*-test was used to compare femoral and tibial tunnel aperture areas at 2 weeks and 6 months. The correlation between bone plug depth and femoral and tibial tunnel enlargement rates and between femoral bone plug position and TTE was evaluated using Pearson's method. On the basis of previous studies in which the average estimated femoral and tibial tunnel enlargement rates were 16.7% and 17.6%, respectively,[2,4] the reference enlargement rates used in this study were set at 0%, 15%, 30%, and 50%. Optimal cutoff values for FBPD and TBPD at each enlargement rate were determined using receiver operating characteristic (ROC) curve analysis. Correlations between femoral and tibial tunnel enlargement rates and each clinical score were assessed using Pearson's method. To evaluate potential confounders affecting tunnel enlargement, subjects were divided into two groups according to FTE ($>15\%$ and $<15\%$); a 15% cutoff value was selected because the mean FTE rate was 16.0% in previous studies.[2,4] Tunnel locations and angles were selected as potential confounders based on previous studies.[19,30,39] Power analysis was performed, as described previously.[4] With an effect size of 0.50 and an α value of 0.05, the calculated power (1-β) was determined as 0.98 in post hoc analysis.

Results

Patient Characteristics

Ninety-eight potential subjects were identified. Of these, 64 met the inclusion criteria (Fig 4). There were 19 females and 45 males with a mean age of 29.5 ± 12.3 years (range: 13−61 years). Mean body mass index was 26.6 ± 4.1 kg/m^2 (range: 18.9−37.9).

Bone Plug Depth and Tunnel Enlargement Rate

Mean FBPD was 4.6 ± 5.0 mm (range: −5.8 to 15.6). Mean TBPD was 8.4 ± 5.8 mm (range: −9.2 to 17.2). Intraobserver reliability ranged between 0.71 and 0.97. Interobserver reliabilities ranged between 0.60 and 0.96. Both femoral and tibial tunnel apertures significantly enlarged over time (Table 1). FBPD and TBPD positively correlated with the rates of FTE and TTE, respectively, with correlation coefficients of 0.607 and 0.308 (Figs 5 and 6). In contrast, FBPD and the TTE rate were not significantly correlated (Fig 7).

Optimal FBPD and TBPD Cutoff Values for Each Tunnel Enlargement Rate

Odds ratios, 95% confidence intervals, and optimal FBPD and TBPD cutoff values for each enlargement rate are shown in Table 2. The optimal FBPD cutoff value was 2.8 mm for FTE rates of 0% and 15%, 3.6 mm for 30%, and 6.0 mm for 50%. The optimal TBPD cutoff value was 1.48 mm for a 0% TTE rate and 5.1 mm for TTE rates of 15%, 30%, and 50%. The areas under the ROC curve and cutoff value specificities were lower for

Table 1. Change of Femoral and Tibial Tunnel Aperture Area

	2W Postoperation	6M Postoperation	Enlargement Rate (%)	*P* Value
Femoral tunnel aperture area (mm^2)	74.2 ± 11.2	96.8 ± 23.1	30.4 ± 30.2 [−19.1, 118.2]	<.01
Tibial tunnel aperture area (mm^2)	66.1 ± 7.5	84.0 ± 17.9	27.0 ± 25.7 [−28.5, 81.0]	<.01

2W post-op, 2 weeks postoperatively; 6M post-op, 6 months postoperatively.

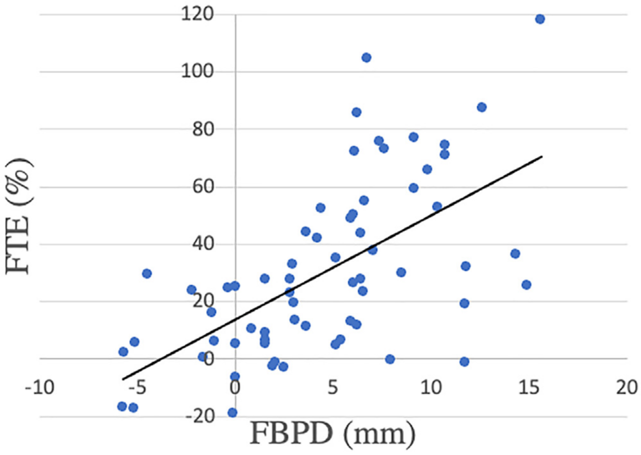

Fig 5. Correlation between femoral bone plug depth and femoral tunnel enlargement rate ($r = 0.607$, $R^2 = 0.369$; $P < .01$). FBPD, femoral bone plug depth; FTE, femoral tunnel enlargement

the tibial tunnel than the femoral tunnel for each tunnel enlargement rate.

Clinical Evaluation

Clinical scores and anterior knee instability results are shown in Table 3. The number of patients meeting the MCID was 18 (28.1 %) on the Tegner activity score, 48 (25.0 %) on the Lysholm score, and 44 (68.8 %) on the IKDC score. The number of patients who met a PASS was 47 (26.6 %). They did not correlate with bone plug position or tunnel enlargement.

Evaluation of Potential Confounders

Comparisons of potential confounders between patients with and without FTE are shown in Table 4. No significant difference was observed between two groups.

Discussion

In the present study, tunnel enlargement and bone plug depth were significantly correlated in both the femoral and tibial tunnels. Moreover, the FBPD cut-off value increased, as the FTE rate increased, especially at FTEs of 30% and 50%. Considering that the 2.8-mm cutoff value did not change between FTE rates of 0% and 15% and then began to increase at 30%, we propose 2.8 mm as the limit for FBPD. Although TBPD was also positively correlated with TTE, the degree of correlation was smaller. In addition, the TBPD cutoff value did not increase in conjunction with expansion of the tibial tunnel aperture, and the specificity was relatively low for each enlargement rate; therefore, the TBPD cutoff values were not reliable. Furthermore, FBPD did not significantly correlate with TTE. Therefore, we conclude that the distal end of the femoral bone plug should be the primary landmark and that the safe zone is shallower than 2.8 mm from the tunnel aperture.

Most studies that have investigated the relationship between the bone plug depth and tunnel enlargement have demonstrated a significantly positive correlation between the two on the femoral side, but not the tibial side.[3,4,10,25] Reported correlations between the two on the tibial side have varied. In our study, bone plug depth was positively correlated with the tunnel enlargement rate on both the femoral and tibial sides. Considering the smaller correlation coefficient on the tibial side, the tibial tunnel aperture may be less affected by bone plug depth than the femoral tunnel aperture. Although the cutoff values we calculated may be useful for determining FBPD, it is unclear what percentage of bone tunnel enlargement has clinical implications. In addition, this study did not find a significant correlation between tunnel enlargement rates and clinical scores. Therefore, the clinical relevance of this study may be limited. Two previous studies[13,15] have recommended two-stage revision if the bone defect is greater than 10 mm and 15 mm, respectively. Alternatively, it is possible that evaluation using bone tunnel diameter may be more relevant than tunnel enlargement rate.

Few reports have examined the optimal location of the femoral bone plug in ACL reconstruction using BPTB grafts or have quantified a safe zone for plug fixation based on bone tunnel enlargement. Our findings suggest that it should be fixed less than 2.8 mm from the tunnel aperture. This is almost the same as fixation of the TBJ precisely at the femoral aperture, which was proposed by Uchida et al.[4] They created a femoral socket inside the tunnel (2 mm longer than the femoral bone plug length) and found it effective for fixing the bone plug precisely at the femoral aperture; moreover, it was highly reproducible. We did not create a femoral socket in the patients of this study because

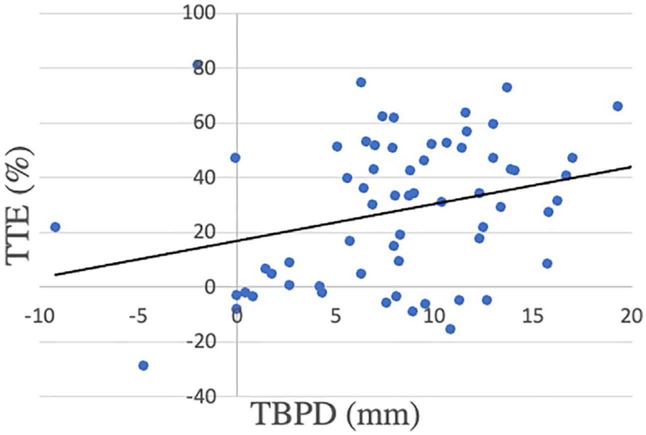

Fig 6. Correlation between tibial bone plug depth and tibial tunnel enlargement rate ($r = 0.308$, $R^2 = 0.095$; $P = .013$). TBPD, tibial bone plug depth; TTE, tibial tunnel enlargement.

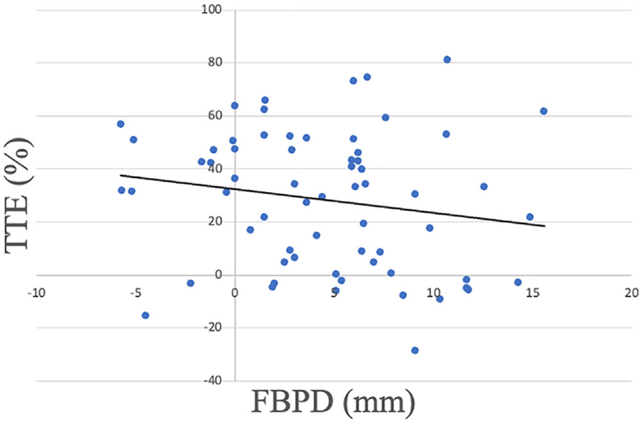

Fig 7. Correlation between femoral bone plug depth and tibial tunnel enlargement ($r = -0.173$, $R^2 = 0.030$; $P = .172$). FBPD, femoral bone plug depth; TTE, tibial tunnel enlargement.

the femoral tunnel was made using the outside-in technique, and the plug position was confirmed arthroscopically. Consequently, FBPD variability was greater in our study. Accordingly, creating a socket may enable more precise fixation. Marking the middle of the tendinous portion of the graft and adjusting it to the center of the joint is also useful; however, this may be associated with a risk of placing the plug too deep. In addition, patellar tendon length is a factor. Therefore, surgeons should pay more attention to the TBJ when fixing the femoral side. Incidentally, using a recently developed femoral suspensory fixation device, which has a length adjustable loop that constricts in one direction[40] may achieve more precise femoral fixation.

Table 2. Odds Ratios, 95% Confidence Intervals, and Optimal Bone Plug Depth Cut-off Values for Each Tunnel Enlargement Rate

FTE Rate (%)	Odds Ratio	95% CI	P Value	FBPD Cutoff Value (mm) (Sensitivity, Specificity)	AUC
0	1.15	0.99−1.34	.07	2.8 (0.73, 0.78)	0.689
15	1.28	1.11−1.47	< .01	2.8 (0.85, 0.67)	0.792
30	1.38	1.16−1.63	<.01	3.6 (0.96, 0.67)	0.847
50	1.33	1.12−1.58	<.01	6.0 (0.94, 0.73)	0.849
TTE rate (%)				TBPD cutoff value (mm) (sensitivity, specificity)	
0	1.12	1.00−1.26	<.05	1.48 (0.94, 0.39)	0.667
15	1.16	1.04−1.30	<.01	5.1 (0.93, 0.50)	0.728
30	1.15	1.03−1.28	<.05	5.1 (0.94, 0.41)	0.672
50	1.03	0.94−1.14	<.50	5.1 (0.94, 0.27)	0.541

AUC, area under the receiver operating characteristic curve; CI, confidential interval; FBPD, femoral bone plug depth; FTE, femoral tunnel enlargement; TBPD, tibial bone plug depth; TTE, tibial tunnel enlargement.

Table 3. Clinical Scores and Anterior Knee Instability Before Surgery and 1 Year After and Numbers of Patients Meeting the Minimal Clinically Important Difference and Patient-Acceptable Symptomatic State

	Before Surgery	1 Year After Surgery
Tegner Activity score	7 [6-9]	7 [6-9]
Lysholm score	67.2 ± 26.1 [0, 100]	89.6 ± 12.0 [46, 100]
IKDC score	52.8 ± 19.6 [4.6, 93.1]	82.0 ± 13.0 [45.8, 100]
SSD on stress radiography (mm)	7.2 ± 4.5 [−0.1, 20.2]	0.9 ± 2.8 [−10.5, 8.4]

The data of Tegner activity score were expressed as medians with interquartile range. Other values were expressed as mean, standard deviation, and range. IKDC, International Knee Documentation Committee, SSD, side-to-side difference.

Limitations

This study has several limitations. First, the causes of tunnel enlargement are multifactorial. We mainly evaluated bone plug depth and did not consider potentially confounding factors such as the tunnel position and bone plug size. Bony healing may be affected by mismatch between plug size and tunnel width. Second, because the fixation device was extracortical, the bone plug may have been rotated over time, which may have caused tunnel enlargement if there was no secure press-fit fixation. Third, although the surgical technique was uniform and procedures were performed in a single facility, 7 surgeons participated in the study; therefore, performance bias may have been present. Moreover, the variation in bone plug depth was greater in this study than in previous ones,[2,4] suggesting considerable inconsistency between

Table 4. Comparison of Potential Confounders Between Patients With and Without Femoral Tunnel Enlargement

	Without FTE* ($n = 24$)	With FTE ($n = 40$)	P Value
Tunnel location			
Femoral shallow wall (%)	31.9 ± 6.1	32.1 ± 5.4	.88
Femoral deep wall (%)	13.2 ± 4.3	13.1 ± 4.5	.94
Femoral high wall (%)	8.5 ± 8.1	9.6 ± 7.3	.60
Femoral low wall (%)	52.9 ± 6.4	53.5 ± 8.6	.75
Tibial anterior wall (%)	23.7 ± 4.0	23.7 ± 4.9	.99
Tibial posterior wall (%)	43.1 ± 4.5	42.6 ± 5.1	.69
Tibial medial wall (%)	43.2 ± 2.9	42.5 ± 5.0	.58
Tibial lateral wall (%)	51.3 ± 2.9	50.8 ± 5.2	.69
Tunnel angles			
Anteroposterior radiographs			
Femoral tunnel angle (°)	27.4 ± 7.5	25.9 ± 9.8	.53
Tibial tunnel angle (°)	69.2 ± 7.9	71.0 ± 5.9	.32
Lateral radiographs			
Femoral tunnel angle (°)	54.2 ± 8.2	53.4 ± 14.8	.81
Tibial tunnel angle (°)	57.0 ± 6.7	56.9 ± 5.2	.97

FTE, femoral tunnel enlargement.

*FTE was defined as ≥15% enlargement between 2 weeks and 6 months after surgery surgeons. These facts are insurmountable and must be taken into serious account. Fourth, despite the unclear impact of bone tunnel enlargement on clinical outcomes, the significance of stratifying bone tunnel enlargement rates at 0%, 15%, 30%, and 50% was not clear. Fifth, the second CT evaluation was performed 6 months after surgery, which may not be a long enough follow-up period to adequately evaluate tunnel widening. Sixth, this study included only patients who underwent rectangular tunnel ACL reconstruction using BPTB with extracortical suspensory fixation; therefore, our findings are limited in generalizability. Seventh, it excluded as many as 35% of patients and was retrospective in design; transfer bias was present. Eighth, although potentially confounding factors did not significantly differ between the patients with and without FTE, propensity score-matched comparisons were not performed.

Conclusion

In patients who underwent rectangular tunnel ACL reconstruction using BPTB autograft with suspensory femoral fixation, early tunnel enlargement and bone plug depth were significantly correlated in both the femoral and tibial tunnels. The degree of correlation was higher in the femoral tunnel. To minimize bone tunnel enlargement, the distal end of the femoral bone plug should be placed less than 2.8 mm from the tunnel aperture.

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