

Comparison of femoral graft bending angle and tunnel length between transtibial technique and transportal technique in anterior cruciate ligament reconstruction

Joon Ho Wang · Jae Gyoon Kim · Do Kyung Lee ·
Hong Chul Lim · Jin Hwan Ahn

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Abstract

Purpose To investigate which technique would reduce bending stress at the femoral tunnel aperture and make short tunnel length after ACL reconstruction by comparing the femoral graft bending angle and tunnel length between the single-bundle (SB) transtibial (TT) and double-bundle (DB) transportal (TP) technique using three-dimensional-computed tomography using OsiriX[®] imaging software.

Methods Forty-nine patients underwent an ACL reconstruction using a SB TT (Group I, 20 patients) and DB TP (Group II, 29 patients) technique. Femoral graft bending angle and femoral tunnel length were measured by CT image using OsiriX[®] imaging software. Groups I and II were compared, and statistical analysis was performed using SPSS software.

Results The mean anteromedial (AM) and posterolateral (PL) femoral graft bending angle of group II ($111.5 \pm 8.8^\circ$ and $118.9 \pm 9.8^\circ$, respectively) was significantly more acute than that of group I ($125.3 \pm 11.1^\circ$) ($P < 0.001$, $P = 0.04$). The mean femoral tunnel length of group I was significantly longer than that of group II ($P = 0.001$).

Conclusions The femoral graft bending angle and the femoral tunnel length of the TP technique performed in the maximally flexed knee position was more acute and shorter than those of the TT technique after ACL reconstruction. This might increase the bending stress at the femoral tunnel aperture and shorter graft length in the tunnel after an ACL reconstruction using TP technique compared to the TT technique.

Level of evidence III.

Keywords Knee · Anterior cruciate ligament · Transportal · Transtibial · 3D-CT · OsiriX

Introduction

Advances in ACL reconstructions have emphasized the importance of placing the graft within their anatomic insertions [13, 28]. A more anatomic femoral tunnel may be positioned better using an independent femoral drilling technique from the tibial tunnel [19], because a difficulty in aiming the femoral tunnel through the tibial tunnel might compromise the positioning of the anatomic femoral tunnel due to a tibial tunnel constraint of femoral drilling [10, 31]. The desire to perform independent drilling while making a femoral tunnel has prompted interest in a transportal (TP) technique and an outside-in technique [3, 18, 19]. The TP technique has many advantages [18]. However, a short femoral tunnel length [21, 23], posterior wall blow-out [18], and graft partial rupture because of the excessive stress on the graft [17, 26] can develop.

One of the factors responsible for graft damage is believed to be repetitive bending stress on the graft at the femoral tunnel aperture due to the abrasive force at the contact area on the sharp edge of the bone tunnel aperture

J. H. Wang · D. K. Lee
Department of Orthopaedic Surgery, School of Medicine,
Sungkyunkwan University, Samsung Medical Center,
Seoul, South Korea

J. G. Kim (✉) · H. C. Lim
Department of Orthopedic Surgery, College of Medicine,
Korea University, Guro Hospital, 80 Guro-dong, Guro-gu,
Seoul 152-703, South Korea
e-mail: jgkim7437@gmail.com

J. H. Ahn
Department of Orthopedic Surgery, School of Medicine,
Sungkyunkwan University, Kangbuk Samsung Hospital,
Seoul, South Korea

[22, 33]. Nishimoto et al. [24] compared the graft bending angle at the femoral tunnel aperture between transtibial (TT) femoral drilling and TP drilling using cadaveric knees using a computer simulation. They suggested that the AM and PL femoral graft bending angles in the TP technique were less acute than in the TT technique. However, when making femoral tunnel with increasing knee flexion angle during the TP technique, the tunnel orientation of the AM and PL femoral tunnel became more horizontal in knee extension [3, 4]. This would make the femoral graft bending angle in extension more and more acute with increasing knee flexion. In addition, to the best of the authors' knowledge, there has not been any clinical in vivo study of the femoral graft bending angle and tunnel length in patients undergoing an ACL reconstruction using TT and TP technique.

Short tunnels can result in reduced graft length within the femoral bone tunnel [37]. Regarding the graft length in the tunnel, many authors suggested that graft length in the tunnel was correlated with the strength of a tendon–bone tunnel complex [11, 37]. Additionally, placement of suspensory fixation device in ACL reconstruction, such as the EndoButton (Smith & Nephew Endoscopy, Andover, MA, US), over the femoral cortex has become popular in recent years. Short tunnel can also cause short graft length in the tunnel in using suspensory device.

The purpose of this in vivo clinical study was to compare the femoral graft bending angle and femoral tunnel-shaft axis angle in the extended knee position and to compare the femoral tunnel length between the TP and TT technique using 3D-CT. It was hypothesized that drilling the femoral tunnel using TP technique in the maximally flexed knee position, as opposed to drilling the femoral tunnel using TT technique, would lead to a more acute femoral graft bending angle and shorter femoral tunnel length.

Materials and methods

Fifty-three consecutive patients underwent an ACL reconstruction using an auto-hamstring tendon graft. Four patients who underwent a revision ACL reconstruction and had multiple ligament injuries were excluded. Patients with isolated primary ACL injury with or without meniscus injury were included in this study. Twenty patients with a less than 6 months interval from the injury time to the operation time were classified as group I and underwent an ACL reconstruction using the remnant preservation single bundle (SB) with the TT femoral tunnel technique. In ACL reconstruction, remnant preservation would be beneficial in terms of proprioception and rapid healing from remnant vascularity, and the status of remnant tissue may be related

to the duration between the injury and surgery [2]. In more acute cases, we thought it would be better to perform remnant preservation, because more sufficient and healthier remnant tissue would remain than in more chronic cases. Twenty-nine patients with over 6 month interval from the injury time to the operation time were classified as group II and underwent an ACL reconstruction using DB with TP technique without remnant preservation. All procedures were performed by a single surgeon.

Patient demographics

The mean age in group I and II was 32.7 ± 9.0 years (range, 17–48 years) and 32.0 ± 10.8 years (range, 15–55 years), respectively (n.s). The mean BMI in group I and II was 25.2 ± 3.6 kg/m² (range, 21.3–27.7 kg/m²) and 26.1 ± 3.4 kg/m² (range, 20.6–28.0 kg/m²), respectively (n.s). The mean time from injury to reconstruction in group I and II was 4.1 ± 1.8 months (range, 0.75–6.0 months) and 29.4 ± 38.6 months (range, 6.25–120.0 months), respectively ($P < 0.001$). The mean preoperative flexion contracture in group I and II was $5.2 \pm 13.2^\circ$ (range, -10 – 50°) and $4.3 \pm 7.7^\circ$ (range, 0– 30°), respectively (n.s). The mean maximum flexion in group I and II was $131.7 \pm 15.4^\circ$ (range, 90– 140°) and $136.5 \pm 6.7^\circ$ (range, 118– 140°), respectively (n.s).

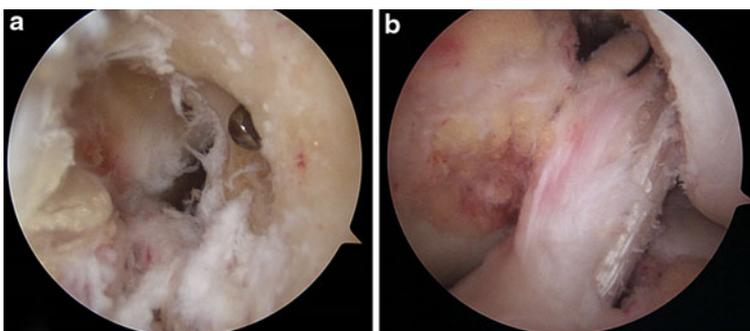
Surgical technique

The portal formation and arthroscopic examinations were conducted in the usual manner. Additionally, we made accessory anteromedial (AAM) portal, which was made at the 1.5 cm medial to the AM portal just above the medial meniscus. The hamstring tendon was harvested. A quadruple (four stranded) graft of semitendinosus and gracilis was made for group I (SB TT). A sextuple (six-stranded) graft, which was composed of triple semitendinosus (for AM bundle) and triple gracilis (for PL bundle), was made for group II (DB TP).

Transtibial tunnel technique (single-bundle reconstruction with remnant preservation) (Fig. 1) [2]

Three No. 0 polydioxanone synthetics (PDS) (Ethicon, Sommerville, NJ, USA) were passed through the remnant ACL tissue. A tibial tunnel was made using an ACL tibial guide (Linvatec, Largo, FL, USA) set at a 45° angle, which enabled to make oblique tibial tunnel and to make femoral tunnel near the anatomic femoral ACL footprint, and the starting point of tibial tunnel was positioned to the point 1 cm medial from the medial margin of tibial tuberosity and 2 cm proximal from the upper margin of pes anserinus tendon [27]. The tip of the tibial guide was positioned to

Fig. 1 Remnant preservation single-bundle anterior cruciate ligament reconstruction using the transtibial technique. **a** The femoral tunnel was made at the point as close as possible to the anatomic foot print of the anteromedial bundle using the transtibial technique. **b** The graft was passed through the femoral tunnel with remnant preservation in front of the graft



the central portion of the remnant tissue. Tibial tunnel reaming was performed through the guide pin. The femoral tunnel was made at the close to the AM femoral footprint from the 10:30 O'clock position for the right knee and 1:30 O'clock position for the left knee at 1–2 mm before the posterior cortex with a femoral guide through tibial tunnel. Subsequently, the usual reaming of the femoral tunnel (30 mm) was performed. For femoral fixation of the graft and remnant tissue, two RigidFix cross pins (DePuy, MitekInc, Raynham, MA, USA) were used. After graft passage, cross pin was fixed, and additional tying of PDS was made at the periosteum of the lateral surface of the entrance of the sleeve if the PDS was not compressed by the cross pin. Finally, the graft was tensioned in full extension before tibial interference screw fixation. Additional distal tibial post-tie fixation was performed in all cases.

Transportal tunnel technique (anatomic double-bundle reconstruction without remnant preservation) (Fig. 2)

After examining the rupture patterns of ACL, the femoral foot prints of both the AM and PL bundles were carefully defined in reference to soft tissue remnant and bony anatomy [8], and marked with a thermal device (Arthrocare, Sunnyvale, CA, USA) and a curved Steadman awl (ConMed [Linvatec], Largo, FL, USA). A Bullseye® femoral guide (ConMed [Linvatec], Largo, FL, USA) was inserted through the AAM portal, and a 3.2-mm guide pin was

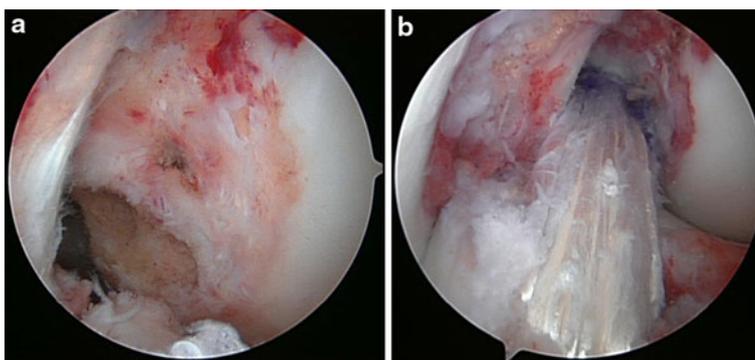
inserted through the Bullseye guide with the tip aiming at the center of the AM and PL bundle femoral insertion site previously defined at maximal knee flexion. A Sentinel cannulated reamer (ConMed [Linvatec], Largo, FL, USA) was introduced over the guide pin and drilled to a 27-mm depth, which enabled graft length in the femoral tunnel 20 mm, and EndoButton (Smith & Nephew Endoscopy, Andover, MA, USA) flipping outside of the femoral tunnel. 4.5-mm EndoButton drill bit (Smith & Nephew Endoscopy, Andover, MA, USA) was then drilled out through the lateral cortex.

Next, a tibial tunnel was made using an ACL tibial guide (Linvatec, Largo, FL, USA) set at 45° for the AM and PL tibial tunnel. The anatomic tibial insertion site of both bundles was marked using an Arthrocare, and the tip of the guide was aimed at the center of the AM and PL bundle remnant tibial insertion site. A 3.2-mm guide pin was inserted into the base of the PL/AM tibial insertion sites. The PL and AM tibial tunnels were then drilled with a cannulated drill. Endobutton was used for femoral fixation, and bio-absorbable interference screw was used for tibial fixation in extension state.

Computed tomography (CT) protocol and measurement

Computed tomography (CT) scans were performed on all knees after the ACL reconstruction with the patients' consent. A computed tomography (CT) scanner Light Speed VCT (GE Medical Systems, Milwaukee, WI, USA)

Fig. 2 Anatomic double-bundle anterior cruciate ligament reconstruction using the transportal technique. **a** The femoral tunnel was made at the anatomic foot print of anteromedial and posterolateral bundle using the transportal technique. **b** The grafts were passed through the femoral tunnel



was used for all examinations. The knee was placed in full extension. The collimation was 16×0.625 mm. The tube parameters were 120 kVp and 200 mA. The acquisition matrix was 512×512 . The field of view was 140 mm, and the slice thickness was 0.625 mm. After extracting the DICOM data from the Picture Archiving and Communication System (PACS), it was imported into OsiriX[®] imaging software (Version 3.8, downloaded from; <http://www.osirix-viewer.com>), which was installed on a Macbook Pro laptop computer (Apple, Cupertino, CA, US). OsiriX is free Digital Imaging and Communications in Medicine (DICOM) software that is used widely in clinical and research fields with comparable efficacy and reliability to commercially available software [34].

The graft bending angle plane in which the centers of the extra- and intra-articular apertures of the femoral tunnel and the center of the intra-articular aperture of the tibial tunnel shown together was selected to measure the bending angle (Fig. 3). To measure the angle between the femoral tunnel axis and femoral shaft axis (femoral tunnel-shaft axis angle), a cross line was set according to femoral shaft axis shown in the sagittal and coronal images. Subsequently, the plane, in which femoral tunnel showed maximal width in the sagittal or coronal images after rotating the cross line on axial image, was selected. The angle between the femoral tunnel axis and cross line, which was set according to the femoral shaft axis and defined femoral tunnel-shaft axis angle, was measured (Fig. 4). To measure the femoral tunnel length, the plane in which the entire length of the femoral tunnel showed the maximal width was selected. This plane was assumed to pass through the center of the tunnel (Fig. 5).

Statistical analysis

Two orthopedic surgeons developed and agreed to the measurement methods together. However, they blinded to

the measurement of each other and also blinded to their own prior measure. They measured the angle and tunnel length of all of the knees twice with an interval of 2 weeks. Reliability of the measurements was assessed by examining the intra- and inter-observer reliability using the intra-class correlation coefficient (ICC). We were unable to estimate the power of the study beforehand. We could not predict the femoral graft bending angle, femoral tunnel-shaft axis angle, and femoral tunnel length, which we needed to estimate the power, because ours was the first in vivo study to compare femoral graft bending angle, femoral tunnel-shaft axis angle, and femoral tunnel length between

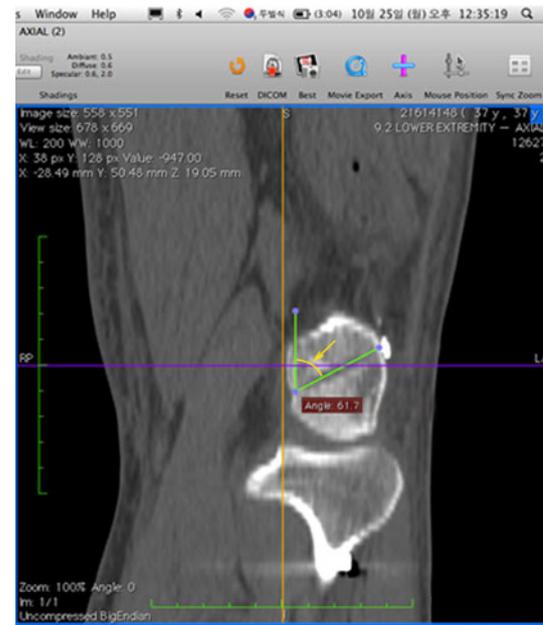


Fig. 4 Femoral tunnel-shaft axis angle was defined as the acute angle between the femoral tunnel axis and femoral shaft axis (yellow arrow). The femoral shaft axis was represented as a yellow colored cross line on OsiriX imaging software

Fig. 3 a The plane for measuring the graft bending angle. We obtained the plane in which the centers of the extra- and intra-articular apertures of the femoral tunnel and the center of intra-articular aperture of the tibial tunnel were shown together. **b** OsiriX image showing the plane for measuring femoral graft bending angle and measurement of the femoral graft bending angle (yellow arrow)

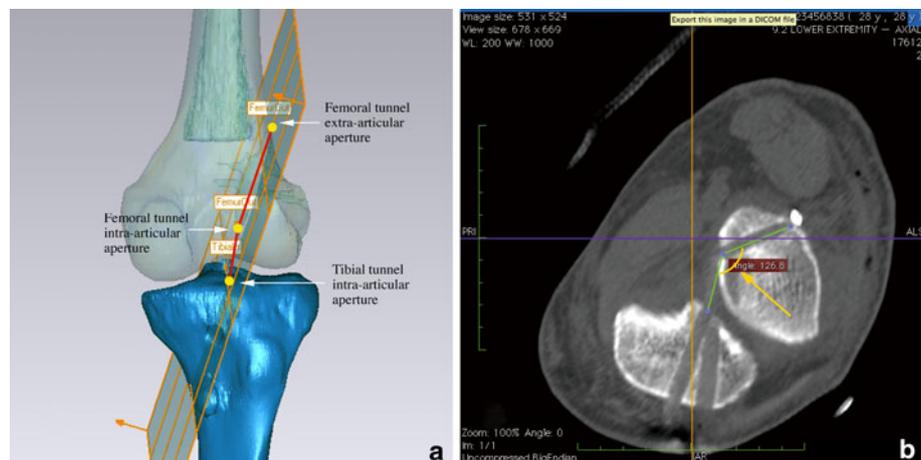




Fig. 5 To measure the femoral tunnel length, the plane in which the entire length of the femoral tunnel showed the maximal width was selected. We measured the distance between the lines, which assumed as intra- and extra-articular aperture margins, in the femoral tunnel

TT technique and TP technique after ACL reconstruction. However, based on results of our study, we conducted a post hoc power analysis, which showed the power between 95 and 99% for a sample of 20 cases of transtibial technique and 29 cases of transportal technique. The post hoc power analysis also showed minimal sample size of $n = 10$ for femoral graft bending angle and femoral tunnel-shaft axis angle, and $n = 15$ for femoral tunnel length. The results of two groups were compared using a two sample t-test and Wilcoxon rank sum test for the graft bending angle, femoral tunnel-shaft axis angle, and femoral tunnel length. Significance was set at $P < 0.05$. Statistical analysis was performed using SPSS software (version 12.0; SPSS, Chicago, IL, USA).

Results

The inter-observer reliability and intra-observer reliability ranged from 0.84 to 0.99 and 0.81 to 0.99, respectively (Table 1).

Comparison of femoral graft bending angle and femoral tunnel-shaft axis angle (Table 2)

The mean femoral graft bending angle of group I was significantly less acute than those of the AM and PL tunnels in group II ($P < 0.001$ for AM, $P = 0.04$ for PL). The mean femoral graft bending angle of the PL tunnel of group II was significantly less acute than those of the AM tunnel of group II ($P < 0.001$). The difference of mean femoral graft bending angle between the TT and TP technique was 13.8° for AM and 6.4° for PL. The mean femoral tunnel-shaft axis angle of group I was significantly smaller than those of the AM and PL tunnel of group II ($P < 0.001$). The mean femoral tunnel-shaft axis angle of PL tunnel was significantly larger than that of the AM bundle in group II ($P < 0.001$).

Comparison of femoral tunnel length (Table 3)

The mean femoral AM and PL tunnel length of group II were significantly shorter than the mean femoral tunnel length of group I ($P < 0.001$). The difference of mean femoral tunnel length between TT and TP technique was 7.7 mm for AM and 7.4 mm for PL. The number of cases with a femoral tunnel length < 30 mm of the AM and PL tunnel in group II was 3 and 3, respectively. Endobutton Direct (Smith & Nephew Endoscopy, Andover, MA) was used in all the cases with femoral tunnel length < 30 mm.

Table 1 Results of ICC value of each measurement

	Femoral graft bending angle		Femoral tunnel–shaft axis angle		Femoral tunnel length	
	AM	PL	AM	PL	AM	PL
Inter-tester						
ICC	0.849	0.868	0.842	0.863	0.997	0.978
Minimum ICC	0.827	0.841	0.811	0.841	0.988	0.956
Maximum ICC	0.898	0.911	0.886	0.899	0.999	0.994
Tester 1						
ICC	0.819	0.891	0.815	0.828	0.998	0.997
Minimum ICC	0.802	0.879	0.779	0.809	0.990	0.988
Maximum ICC	0.879	0.935	0.877	0.868	0.999	0.999
Tester 2						
ICC	0.879	0.926	0.868	0.881	0.995	0.992
Minimum ICC	0.864	0.901	0.832	0.857	0.989	0.983
Maximum ICC	0.964	0.988	0.901	0.909	0.999	0.999

A measurement was considered reliable if the ICC was higher than 0.80

ICC intra-class correlation coefficient, AM anteromedial, PL posterolateral

Table 2 Comparison of the femoral graft bending angle and femoral tunnel-shaft axis angle between group I and II

	Group I (n=20 knees)	Group II (n=29 knees)	<i>P</i> ^a	<i>P</i> ^b
Femoral graft bending angle	AM	111.5 ± 8.8 (93.6~130.7)	< 0.001	< 0.001
	PL	125.3 ± 11.1 (106.9 ~ 143.1)	n.s	
Femoral tunnel-shaft axis angle	AM	51.4 ± 7.4 (40.8 ~ 72.0)	< 0.001	< 0.001
	PL	40.6 ± 8.1 (24.9 ~ 56.8)	<0.001	

The values are in degrees:
mean ± SD (range)

AM anteromedial, PL posterolateral

^a Comparison between transtibial and transportal technique

^b Comparison between AM tunnel and PL tunnel in group II

Table 3 Comparison of the femoral tunnel length between the singlebundle transtibial (SB TT) and double-bundle transportal (DB TP) techniques

Tunnel length	Group I (n = 20 knees)	Group II (n = 29 knees)	<i>P</i> ^a
Femur			
AM	41.6 ± 8.9 (33.7 ~ 60.5)	33.9 ± 3.2 (26.4 ~ 40.0)	0.001
PL		34.2 ± 3.4 (28.7 ~ 42.4)	0.001

The values are in millimeters : mean ± SD (range)

AM anteromedial, PL posterolateral

^a Comparison between transtibial and transportal technique

Discussion

The most important finding of the present study was that the femoral graft bending angle of the SB TT group (group I) was less acute than DB TP group (group II), as hypothesized. As far as we know, only one study compared the tunnel geometry in the TT and TP techniques. Nishimoto et al. [24] compared the femoral graft bending angle between the TT and TP technique in cadaveric knees using a virtual computer simulation. However, the present study was performed with patients undergoing an ACL reconstruction using the SB TT and DB TP techniques to evaluate the femoral graft bending angle and tunnel length using 3D-CT. In contrast to our results, Nishimoto et al. [24] proposed that the AM and PL femoral graft bending angles of the TT group were significantly more acute than those of the TP group. They also suggested that the TP technique might result in lower stress on the graft at the femoral tunnel aperture and might reduce graft damage. However, there were some differences between this study

and Nishimoto's study. First, their study was an in vitro study using cadaveric knees, and they used a three-dimensional virtual computer simulation to make a virtual graft and virtual tunnel. Second, they defined the virtual femoral tunnel in the TT technique as an extended line of virtual AM and PL grafts at 90° of flexion without considering the position of the tibial tunnel. Third, in the TP technique, they fixed the position of the far anteromedial portal without considering the notch shape and condyle size. Finally, they set the knee flexion angle to 110° when making the femoral tunnel using TP technique, which is in contrast to the maximally flexed knee position in the present study.

After the ACL reconstruction, the cause of graft damage was multifactorial, such as the graft diameter, type of graft, graft tensioning and fixation, impingement of the graft against the intercondylar notch and PCL, and the repetitive bending stress on the graft at the femoral tunnel aperture [13, 14, 22, 24, 33]. One of the factors responsible for graft damage is believed to be the repetitive bending stress on the graft at the femoral tunnel aperture, due to the abrasive force at the contact area on the sharp edge of the bone tunnel aperture when the graft is acutely bent and stretched [22, 33]. In a PCL reconstruction, Bergfeld et al. [5] suggested more severe wearing and loosening of the graft with a transtibial PCL reconstruction after cyclic loading, supporting the efficacy of a tibial inlay reconstruction in achieving posterior stability of the knee. In an ACL reconstruction, it is also hypothesized that the femoral graft bending angle would affect the amount of graft damage after an ACL reconstruction. The repetitive bending stress on the graft and graft micromotion is also believed to be responsible for tunnel enlargement [20, 30]. Segawa et al. [30] suggested that the femoral tunnel angle was significantly more acute in patients displaying femoral tunnel

enlargement than in patients without femoral tunnel enlargement. Graft placement is challenging during revision ACL reconstruction particularly when bone loss is present [20].

The mean femoral graft bending angle in group I was larger, and the mean femoral tunnel-shaft axis angle in group I was smaller than the mean AM and PL femoral graft bending angle in group II. The hypothesis in the present study was that the femoral graft bending angle would be more acute than the TT technique if the femoral tunnel is made using the TP technique in the maximally flexed knee position in an ACL reconstruction. In a PCL reconstruction, some authors reported the “killer turn effect” at the tibial tunnel aperture after a transtibial PCL reconstruction [5]. Huang et al. [12] measured graft bending angle at the tibia using anteromedial route in transtibial PCL reconstruction. They showed that graft bending angle at the tibia was $81.0 \pm 2.7^\circ$ using anteromedial route and $114.4 \pm 3.2^\circ$ using anterolateral route at 90° of knee flexion and recommended anterolateral route in transtibial PCL reconstruction. Kim et al. [16] also compared clinical result between anteromedial and anterolateral route. The mean side-to-side difference of posterior tibial translation showed statistically significant difference between two routes. However, as far as we are aware, there is no study to show clinical results comparing sharp and blunt graft bending angle in ACL reconstruction. In the present study, the difference of mean femoral graft bending angle between the TT and TP technique was relatively small, and we did not compare clinical results between two groups. Therefore, we were unable to conclude that TP technique would show poor clinical result compared to TT technique because of small difference of mean graft bending angle. However, in group II, minimum graft bending angle of AM/PL was 93.6° and 91.7° , respectively, and maximum difference of AM/PL femoral graft bending angle between TT and TP technique was 49.5° and 51.4° , respectively. Therefore, in such cases possibly, acute femoral graft bending angle might be problem.

There is some controversy regarding the degree of knee flexion during drilling of the femoral tunnel in an ACL reconstruction using the TP technique. Some authors recommended drilling the femoral tunnel through the AM portal in full flexion [9, 19]. However, they did not consider the angular change in the femoral tunnel according to the knee flexion angle. Some authors recommended 110° , 120° , or 130° of flexion when drilling the AM tunnel through the AM portal [3, 15, 28, 32]. Basdekis et al. [3, 4] examined the effect of the knee flexion angle for drilling the femoral tunnel during ACL reconstruction via the AM portal on the resulting tunnel orientation and length. With regard to the AM and PL tunnel orientation, each increase in knee flexion angle resulted in a significantly more

horizontal tunnel. They recommended that the femoral tunnel be drilled after the knee was flexed to 110° in the TP technique. With 130° of knee flexion and maximum flexion, they also showed the acuity of the tunnel resulting in a higher contact pressure on the graft and tunnel wall [3]. In the present study, a femoral tunnel was drilled through the AAM portal after the knee was flexed to the maximum degree (Fig. 6). This may also make a more acute femoral graft bending angle than that of the TT technique.

In the present study, the mean AM femoral graft bending angle and femoral tunnel-shaft axis angle in the TP group were smaller than the mean PL femoral graft bending angle and femoral tunnel-shaft axis angle in the TP group. Nishimoto et al. [24] also reported that the mean AM femoral graft bending angle was more acute than the mean PL femoral graft bending angle in the TP group. In many studies, each bundle was at the greatest length at full extension, and the relative change in the PL bundle was significantly larger than that of the AM bundle at a low flexion angle [24, 36]. Therefore, PL bundle might be subject to more excessive stress from the femoral tunnel [29]. Otsubo et al. [26] reported complete or partial rupture in 11% of PL grafts at the femoral tunnel aperture after an anatomic ACL reconstruction, and the AM graft was free from graft damage after the anatomical DB ACL reconstruction. Therefore, the AM femoral graft bending angle might not affect the level of graft damage than the PL femoral graft bending angle, even though the mean AM femoral graft bending angle was more acute than the mean PL femoral graft bending angle in the present study. However, a smaller femoral graft bending angle is undesirable in the TP technique, even though the PL femoral



Fig. 6 While making the femoral tunnel using the transtibial portal technique, the guide pin was advanced all the way through the opposite cortex and skin in the maximally flexed position

graft bending angle is less acute than AM femoral graft bending angle.

The femoral tunnel length of group II was shorter than that of group I. The reported risk of the TP technique for ACL femoral tunnel creation was a short tunnel length [21, 23]. Miller et al. [21] reported that the length of the femoral tunnel using TP technique was shorter than that using TT technique. Chang et al. [6] suggested that the femoral tunnel made via the TP technique would be placed more horizontally within the femur, which reduces the tunnel length. Golish et al. [10] also suggested that the horizontal femoral tunnel starting position reduced the tunnel length substantially. Moreover, in the TP technique, the tunnel length changed according to the knee flexion angle. Baskedakis et al. [3] observed a significantly shorter AM femoral tunnel length at knee flexion of 90° compared to 110°, 130°, and maximum flexion (27.1 mm at 90° flexion, 38.9 mm at 110°, 38.8 mm at 130°, and 39.2 mm at maximal flexion). Therefore, to prevent a short femoral tunnel, particularly the AM tunnel, in the TP technique, it is not necessary to make a femoral tunnel in the maximally flexed knee position, which also will make femoral graft bending angle more acute.

Short tunnels can result in reduced graft length within the femoral tunnel [37]. The difference of mean femoral tunnel length between TT and TP technique was 7.7 mm for AM and 7.4 mm for PL. It may be small. However, the minimum femoral tunnel length of group II was 26.4 mm for AM and 28.7 mm for PL compared to 33.7 mm of minimum femoral tunnel length of group I. In using suspensory fixation device such as EndoButton, short femoral tunnel length would dramatically induce short graft length in the tunnel for the length of suspensory fixation device. Regarding the graft length in the tunnel, Greis et al. [11] suggested in a canine model that maximizing the tendon length within a bone tunnel would maximize the strength of a tendon–bone tunnel complex at 6 weeks. However, Zantop et al. [37] suggested in a goat model that reducing the graft length in the femoral tunnel until 15 mm did not have adverse effects. Yamazaki et al. [35], who examined a canine model, reported no significant differences between graft length of 15 and 5 mm in the tunnel and tendon to bone healing occurred at the aperture site. There is little evidence to make a specific recommendation of the precise graft length in the tunnel [7]. However, there is also a lack of evidence on whether a graft length in the tunnel <15 mm can be safely used in an ACL reconstruction, particularly for humans [11, 35, 37]. In the TP technique, the Endobutton system was used. The minimal loop length of the Endobutton CL system was 15 mm. If the tunnel length was <30 mm, the graft length in the tunnel would be <15 mm, which might compromise the healing process [11, 35, 37]. Therefore, the Endobutton Direct system was

used in cases with a femoral tunnel length <30 mm, which enabled a short graft length in a tunnel <15 mm.

There were several limitations in this study. First, the femoral graft bending angle could not be evaluated in various degrees of knee flexion, but it was evaluated in the extended knee position. Many authors suggested that an AM and PL bundle is the greatest length at full extension, so tension increases maximally in that position [24, 36]. Therefore, checking the 3D-CT in extended knee position is very meaningful. Second, we compared between SB with remnant preservation and DB. In remnant preservation technique, Adachi et al. [1] reported good results from the viewpoint of position sense and joint stability. Ochi et al. [25] also suggested that the vascularity of the remnant tissue has a favorable effect on the graft. Ahn et al. [2] described that although the ratio of the remnant ACL patterns may be related to the duration between the injury and surgery as well as the number of giving way episodes, more than half of patients have remnant tissue that is valuable for proprioception and have a favorable influence on the vascularity. In more acute cases, we thought that it would be better to perform remnant preservation, because more sufficient and healthier remnant tissue would remain than in more chronic cases. If we used remnant preservation technique, it would be better to perform SB reconstruction for technical difficulty and possibility of remnant tissue damage in DB reconstruction with remnant preservation. Third, the patients were divided into two groups not by randomization, but by the interval from the injury time to the operation time. The cause of this division is the status of remnant ACL as previously described. And the patients in both groups did not show arthritic changes that might not deform the bony morphology. Therefore, the tunnel direction and angle was not affected by the surgical intervention interval. Fourth, we could not compare clinical result and second look arthroscopic findings between SB TT and DB TP. Therefore, we could not provide some form of justification of superiority of two techniques for the relatively small differences in graft bending angle and tunnel length as to whether there would be a clinical consequence of this difference.

The femoral graft bending angle and the femoral tunnel length of the TP technique performed in the maximally flexed knee position was more acute and shorter than those of the TT technique after ACL reconstruction. It might be better to perform femoral tunnel drilling in the less flexed knee position to make less acute femoral graft bending angle; however, it is also necessary to flex the knee to prevent short femoral tunnel in ACL reconstruction using TP technique. Therefore, further studies are required in future to answer which flexion degree of knee joint would be more appropriate to make less acute femoral graft bending angle and to prevent short femoral tunnel length in ACL reconstruction using TP technique.

Conclusion

The femoral graft bending angle and the femoral tunnel length of the TP technique performed in the maximally flexed knee position was more acute and shorter than those of the TT technique after ACL reconstruction. This might increase the bending stress at the femoral tunnel aperture and shorter graft length in the tunnel after an ACL reconstruction using TP technique compared to the TT technique.

Conflict of interest No conflicts of interest present in this study.

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