

# The Effect of Different Sagittal Angles of the Tibial Guide on Aperture Widening of the Tibial Tunnel during Modified Transtibial Anterior Cruciate Ligament Reconstruction: A Randomized *In Vivo* Study

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**Purpose:** The effect of sagittal plane angle of the tibial tunnel on the severity of tibial intra-articular aperture expansion caused by iatrogenic re-reaming in anterior cruciate ligament (ACL) reconstruction using a modified transtibial technique is unknown. The purpose of this study was to compare the severity of intra-articular aperture widening at different angles (40°, 45°, and 50°) of the tibial guide (TG).

**Materials and Methods:** Ninety-seven patients who underwent modified transtibial ACL reconstruction were randomly allocated to TG 40°, 45°, and 50° groups. Intra-articular tibial aperture width (TW) and tibial tunnel length (TTL) were measured intraoperatively using an arthroscopic ruler and a depth gauge.

**Results:** The TG 50° group had significantly greater tibial aperture widening than the TG 40° group. There was a significant difference among TG 40°, 45°, and 50° groups and the percentage of knees with TTL <35 mm was 8%, 9% and 3%, respectively. There were 2 females with TTL <35 mm in TG 40° and 45° groups each. The average mediolateral length of the tibial plateau was 75 mm.

**Conclusions:** This study shows that the TG angle of 40° would reduce the severity of intra-articular aperture widening of the tibial tunnel compared to 45° or 50° in modified transtibial ACL reconstruction.

**Keywords:** Knee, Anterior cruciate ligament, Reconstruction, Tibial tunnel, Aperture widening

## Introduction

Optimal tunnel placement and graft alignment are important factors associated with successful outcomes of anterior cruciate ligament (ACL) reconstruction<sup>1,2)</sup>. However, one of the major

limitations of the transtibial technique for ACL reconstruction is that the femoral tunnel cannot be placed properly inside the intercondylar notch because of its dependency on the tibial tunnel. Improper alignment and placement of a graft within tunnels created by the transtibial technique may result in graft impingement, graft-tunnel mismatch or tibial aperture widening<sup>3-7)</sup>. The risk of tibial intra-articular aperture expansion caused by iatrogenic re-reaming of the tibial tunnel has been reported as a major disadvantage of the transtibial technique<sup>3,8)</sup>, which may also lead to a graft-tunnel mismatch and a delay in incorporation of the graft<sup>9)</sup>. In addition, a short tibial tunnel could impair fixation and incorporation of a graft, resulting in a tunnel length-graft length mismatch<sup>5)</sup>.

In the transtibial technique, the direction of the guidewire determined as the optimal trajectory toward the anatomical femoral footprint may cause iatrogenic re-reaming of the tibial tunnel and

Received June 15, 2016; Revised November 5, 2016;

Accepted December 10, 2016

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significant intra-articular aperture expansion due to its eccentric and posterolateral positioning within the tibial tunnel<sup>3)</sup>.

Several studies have suggested modifications to the coronal plane alignment of the tibial tunnel in the transtibial technique for accurate femoral tunnel positioning and minimal errors<sup>4,6,10-12)</sup>. However, the literature is lacking on the effect of variation in the sagittal plane angle of the tibial tunnel in relation to the severity of tibial intra-articular aperture expansion caused by iatrogenic re-reaming in ACL reconstruction using the modified transtibial technique. To the best of our knowledge, there has not been sufficient research suggesting the best sagittal plane angle. Thus, we assumed that the appropriate angle would be between 40° and 50° to evaluate the effect of variation in the sagittal plane angle of the tibial tunnel on tibial intra-articular aperture expansion.

The purpose of this study was to investigate the severity of intra-articular aperture widening and proportion of knees with a tibial tunnel length (TTL) less than 35 mm at different angles of the tibial guide (TG) in ACL reconstruction using the modified transtibial technique. We hypothesized that drilling the tibial tunnel with the TG set at different angles would result in differences in the severity of intra-articular aperture widening of the tibial tunnel.

## Materials and Methods

Initially, 121 patients who underwent primary arthroscopic single bundle ACL reconstruction with a hamstring tendon autograft using the transtibial technique at a single institution were recruited for this prospective, randomized controlled study. This study was approved by the Institutional Review Board of our hospital. The inclusion criteria were: 1) unilateral ACL rupture, 2) age between 18 and 50 years, 3) a normal contralateral knee, and 4) informed consent by patients for participating in this study. The exclusion criteria were concomitant ligament injuries (based on clinical and magnetic resonance imaging examinations) and cartilage degeneration greater than Outerbridge grade 2 (based on intraoperative arthroscopic assessment). Of the 121 patients, 102 patients agreed to take part in the study, 2 of which were excluded from the study due to associated ligament injuries. Ultimately, 100 patients were enrolled in the study and randomly allocated to one of the three groups based on the sagittal angle of TG (40°, 45°, or 50° group) using a computerized random number table. An envelope was used to conceal the randomization sequence.

Associated meniscal injury was noted at the time of reconstruction in 18 knees in the TG 40° group, in 19 knees in the TG 45°

group and in 17 knees in the TG 50° group. Three patients were excluded from the study since cartilage degeneration greater than Outerbridge grade 2 was found on intraoperative arthroscopic assessment. Hence, the final analysis was based on the data obtained from a total of 97 patients: 34 patients (34 knees) in the TG 40° group, 32 patients (32 knees) in the TG 45° group and 31 patients (31 knees) in the TG 50° group (Fig. 1). There was no statistically significant difference in patient demographics among the three groups (Table 1).

## 1. Surgical Technique

A single surgeon performed the arthroscopic single bundle ACL reconstruction with a hamstring tendon autograft using the transtibial technique in all cases. After diagnostic arthroscopy, any meniscal lesion was treated before reconstruction. Both the semitendinosus and gracilis tendons were harvested using a tendon stripper and were prepared as a four-stranded double-looped hamstring autograft. The mean diameter of the double-looped semitendinosus and gracilis tendon autograft was 7.3 mm (range, 6.5 to 7.9 mm). The ACL TG (ConMed Linvatec, Largo, FL, USA) was set at 40°, 45°, or 50° for tibial tunneling according to the group allocation (Fig. 2). The starting point was uniformly created in the coronal plane of the tibial tunnel at midway between the posterior cortex of the proximal tibia and the medial margin of the tibial tuberosity to minimize the effect of coronal orientation of the guide angle on the size of tibial aperture. The intra-

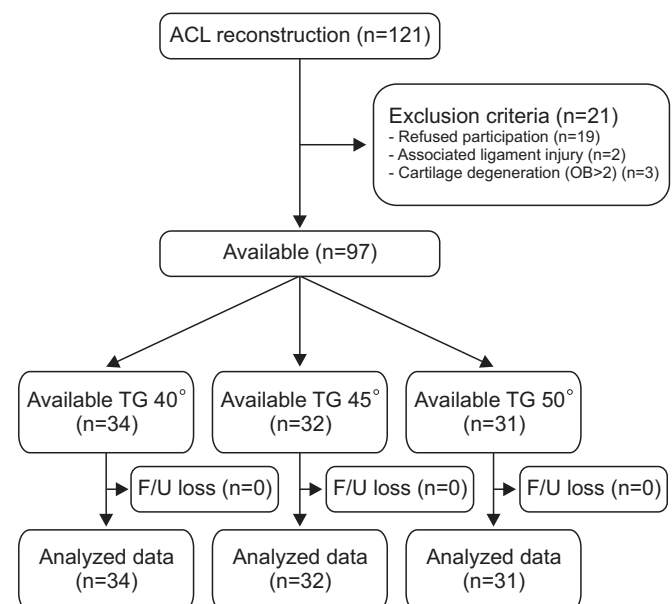


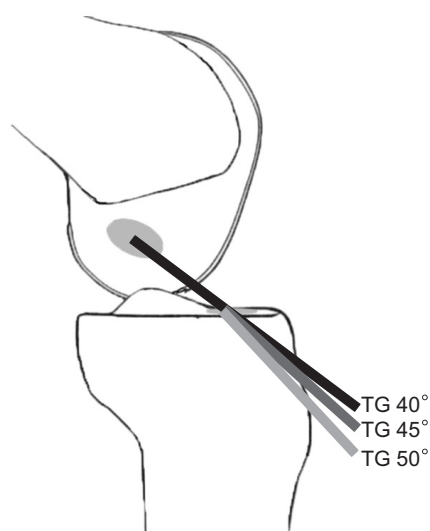
Fig. 1. Flow diagram of the study. ACL: anterior cruciate ligament, OB: Outerbridge, TG: tibial guide, F/U: follow-up.

**Table 1.** Comparison of Demographic Characteristics and Mediolateral Width of the Proximal Tibia among the TG 40°, 45°, and 50° Groups

Parameter	TG 40°	TG 45°	TG 50°	p-value
No. of female subjects	6	6	6	0.75
Age (yr)	31±11 (17–30)	38.5±15 (17–75)	36±11 (17–59)	0.06
Height (cm)	171±8 (152–184)	168±8 (151–182)	171.5±7.5 (150–182)	0.29
Weight (kg)	71±13 (50.0–99.0)	70.5±12 (50.0–90.0)	73±8.6 (53.8–86)	0.70
Meniscus procedure (meniscectomy/repair/none)	10/6/18	14/5/13	10/7/14	0.73
Mediolateral size (mm)	84±6 (71.3–97.0)	84.5±7 (70.0–95.4)	86±7 (68.0–95.5)	0.49

Values are presented as mean±standard deviation (range).  $p < 0.05$  is statistically significant.

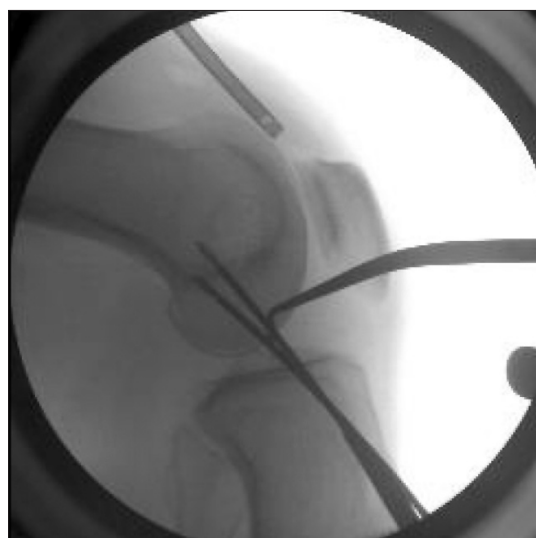
TG: tibial guide.



**Fig. 2.** Schematic drawing showing the sagittal plane angle of the tibial guide (TG) at 40°, 45°, and 50°.

articular point of the TG was placed at the center of the native tibial footprint of the ACL. To minimize errors and standardize the orientation of TG, the tip of TG was maintained perpendicular to the tibial slope under fluoroscopic guidance before drilling the guidewire (Fig. 3). The diameter of the tibial and femoral reamers used was the same as that of the graft and a 7 mm offset size of the femoral guide was used.

After reaming of the tibial tunnel, the longest axis of the intra-articular tibial aperture width (TW) was measured using an arthroscopic ruler (ConMed Linvatec) under direct arthroscopic visualization (Fig. 4). The position of the ruler was aligned parallel to the tunnel aperture and was confirmed under arthroscopic visualization. Similarly, TTL was also measured at the shortest aspect of the tunnel using a depth gauge. In the position of 90° knee flexion and neutral tibial rotation, the femoral offset aimer (ConMed Linvatec) was then passed through the tibial tunnel, and its hook was placed at around the 10:30 clock position (right



**Fig. 3.** Intraoperative fluoroscopic image of a tibial guide set at 40° and 45°. Note that the guide tip is placed perpendicular to the joint surface as confirmed by fluoroscopy.

knee)/1:30 clock position (left knee) at the over-the-top area of the lateral intercondylar notch. This position was maintained for the same femoral tunnel location in all groups. The femoral aiming guide was rotated laterally so that the femoral tunnel could be placed more anatomically<sup>12,13</sup>. Finally, a 2.4-mm guide pin with a suture eyelet was inserted, and the femoral tunnel was drilled. After reaming of the femoral tunnel transtibially, TW was remeasured using an arthroscopic ruler (Fig. 5). The difference in TW assessed before and after formation of the femoral tunnel was calculated and recorded as tunnel aperture widening. Tibial width was measured as the distance between the medial border and the lateral border of the tibial plateau on the anteroposterior standing X-ray view according to Yoon et al.<sup>14</sup>. To evaluate the reliability of arthroscopic measurements using the arthroscopic ruler, three-dimensional computed tomography (CT) scans (Aquilion One; Toshiba Medical Systems Cor., Otawara, Japan) using PACS view

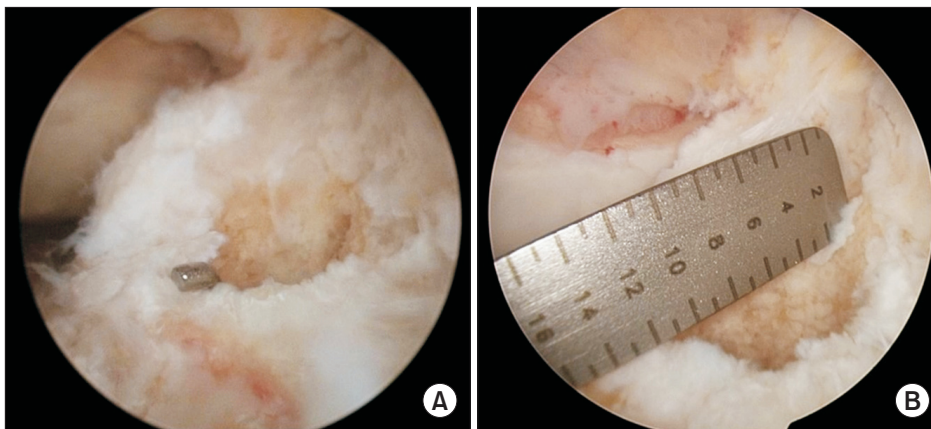


Fig. 4. Measurement of tibial tunnel length (A) and aperture widening (B) during arthroscopy.

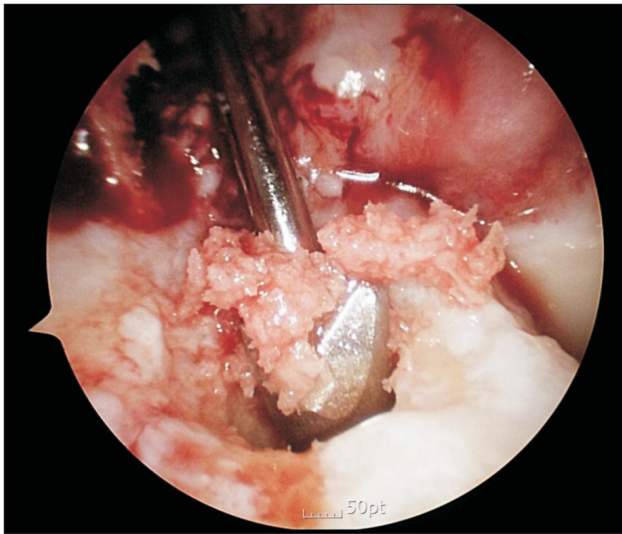


Fig. 5. Arthroscopic image showing eccentric posterolateral re-reaming of the tibial tunnel causing widening of the aperture.

(PACS; Marotech Inc., Seoul, Korea) were evaluated in 20 knees at postoperative 1 week and compared with the arthroscopic measurement values of TW obtained intraoperatively.

The fixation technique for the femoral side and the tibial side was the same in all groups. After passing through the femoral tunnel, the graft was secured using the RigidFix system (DePuy Mitek, Raynham, MA, USA). Once the graft had been secured on the femoral side, the knee was positioned in 10° flexion and both loops were placed on the Intrafix tie tensioner (DePuy Mitek) with 25 lb force. The tibial end of the graft was then fixed using an Intrafix biodegradable screw (DePuy Mitek) supplemented by a screw and spiked washer.

Patients in all three groups followed an identical accelerated postoperative rehabilitation regimen. Closed chain kinetic exercises were started on the third postoperative day and full weight

bearing exercises on the seventh postoperative day. Patients who underwent a concomitant meniscal repair walked on crutches with partial weight bearing for 6 weeks. The goal for all patients was to gain a full range of motion at the end of 6 weeks after surgery. All patients were assessed for function using the International Knee Documentation Committee (IKDC) score and Lysholm score both preoperatively (on admission) and postoperatively (at 2-year follow-up). Knee joint laxity was quantitatively measured using the KT-2000 arthrometer (MEDmetric, San Diego, CA, USA) with a standard manual force of 134 N applied both preoperatively and postoperatively.

## 2. Statistical Analysis

A power analysis was performed before commencing the study to determine the sample size based on our preliminary data. The sample size was calculated to be 26 subjects in each group for a power of 80% and a significance level of 0.05. Wilcoxon rank sum test was used to analyze differences in the average TW between the CT measurement and the arthroscopic ruler measurement. The differences in TW and TTL among the 3 groups of TG 40°, 45°, and 50° were analyzed using one-way analysis of variance test followed by multi-comparison test using Bonferroni test. The proportions of cases with a TTL less than 35 mm in the three groups were calculated and then compared by Fisher exact test. Clinical scores (Lysholm score and IKDC score) and KT-2000 measurements (134 N posterior load was applied to the posterior aspect and the anterior translation distance was measured) of patients during preoperative and postoperative evaluation were compared among the 3 groups using Mann-Whitney *U* test. All statistical analyses were performed with SPSS ver. 18.0 (SPSS Inc., Chicago, IL, USA) and *p*-values of <0.05 were considered statistically significant.



Results

Different TG angles resulted in different TW ( $p=0.01$ ) and TTL ( $p=0.03$ ). The intra-articular aperture of the tibial tunnel due to iatrogenic re-reaming was approximately 1.5 times greater in the

TG 50° group (mean, 3.4 mm) than in the TG 40° group (mean, 2.2 mm) ( $p=0.01$ ) (Table 2). The aperture width of the TG 50° group was significantly greater than that of the TG 40° group in the post hoc test ( $p<0.01$ ). There were statistically significant differences in TTL among the TG 40°, TG 45°, and TG 50° groups

Table 2. Comparative Results of Tibial Tunnel Length and Tunnel Aperture Widening

Parameter	TG 40°	TG 45°	TG 50°	p-value
Graft size (mm)	7.1±0.3	7.2±0.5	7.3±0.5	0.43
Tibial tunnel length (mm)	38.8±3.1 (34–43)	40.1±2.8 (34–45)	42.0±2.8 (34–47)	0.03
Tibial tunnel widening (mm)	2.24±1.3 (1–8)	2.78±1.8 (1–8)	3.36±1.4 (1–8)	0.01

Values are presented as mean±standard deviation (range).  $p<0.05$  is statistically significant.  
TG: tibial guide.

Table 3. Comparison of Preoperative and 2-Year Postoperative Clinical Data among the TG 40°, 45°, and 50° Groups

Parameter	TG 40°		TG 45°		TG 50°	
	Preop	2-yr F/U	Preop	2-yr F/U	Preop	2-yr F/U
No. of patients	34		32		31	
Lysholm score	61.2±9.8	93.3±3.5	58.3±8.5	90.2±8.3	59.5±10.4	92.8±5.5
IKDC score	40.6±6.3	77.9±6.5	38.8±4.7	76.3±6.1	41.9±5.7	76.1±5.6
KT-2000 (side-to-side difference)	8.2±2.6	1.7±1.5	7.8±1.8	1.5±1.2	8.5±2.2	1.8±1.4

Values are presented as mean±standard deviation.  
TG: tibial guide, Preop: preoperative, F/U: follow-up, IKDC: International Knee Documentation Committee.

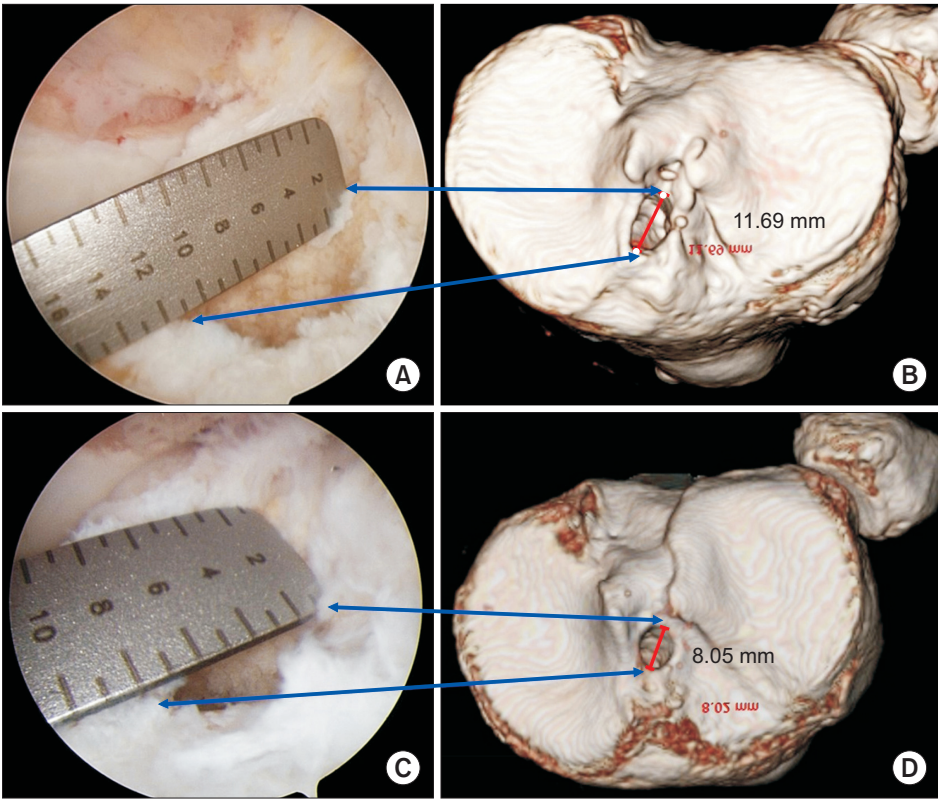


Fig. 6. Measurement of the tibial aperture using an arthroscopic ruler (A, C) and three-dimensional computed tomography (B, D).

( $p=0.03$ ) (Table 2). The number of knees with TTL measuring less than 35 mm was 3 (8%) in the TG 40° group, 3 (9%) in the TG 45° group and 1 (3%) in the TG 50° group, showing no statistically significant intergroup difference ( $p>0.05$ ). There were 2 female patients with TTL measuring less than 35 mm in the TG 40° group and TG 45° group each. The average length of the mediolateral tibial plateau was 75 mm. There were no cases with TTL measuring less than 30 mm in all groups. Clinical outcomes were not significantly different among the 3 groups (Table 3). The average width of the longest axis of the intra-articular aperture measured by the arthroscopic ruler and by CT was 9.52 mm and 9.48 mm, respectively, showing no statistically significant difference ( $p>0.05$ ) (Fig. 6).

## Discussion

The most important finding of this study was that drilling the tibial tunnel with the TG set at 40° would reduce the severity of intra-articular aperture widening of the tibial tunnel during primary ACL reconstruction using the transtibial technique. The severity of aperture widening was significantly greater after ACL reconstruction performed with the TG set at 50°.

The interface between the tunnel aperture and graft is an important factor in kinematics of a reconstructed ligament<sup>8,15</sup>. Bedi et al.<sup>3</sup> in their cadaveric study reported that iatrogenic posterolateral re-reaming of the tibial tunnel with the TG set at 55° resulted in expansion of the tibial aperture by 38% after ACL using the transtibial technique. They attributed such results to the eccentric posterolateral positioning of the femoral guide pin within the tibial tunnel, which was inevitable to optimize the trajectory toward the anatomical footprint of ACL. Our study compared the differences in TW at different sagittal angles of the TG and demonstrated that a greater sagittal angle of the TG caused more widening of the tibial aperture.

Our study also showed that TLL was significantly different among the TG 40°, 45°, and 50° groups. Although the transtibial technique has been reported to produce the most vertical and longest femoral tunnel compared to independent drilling techniques, this technique has been associated with less anatomic positioning of the tunnel<sup>7</sup>. Various techniques designed for better anatomic position of the tunnel may reduce the tunnel length, increasing the risk of postoperative complications such as graft-tunnel mismatch and protrusion of the screw inside the joint<sup>16</sup>. In a cadaveric study, Heming et al.<sup>5</sup> attempted to produce tibial and femoral tunnels at the center of the native footprint using the transtibial technique. However, they reported that the technique

resulted in shortening of the tibial tunnel (range, 30 to 32 mm). In contrast, we adjusted the sagittal angle of the tibial tunnel in this study, which resulted in a relatively long tibial tunnel with a mean length of 38.2 mm (range, 34 to 37 mm). This could be attributable to the difference with the study by Heming et al.<sup>5</sup> in terms of the coronal angle of the tibial tunnel and slightly posterior target position of the femoral tunnel.

In contrast, a recent study by Wallace et al.<sup>17</sup> reported that when the tibial drill guide was set at an angle of 45°, 50°, and 55°, the mean TTL was 47.3 mm, 48.9 mm, and 50.3 mm, respectively. They concluded that there was no significant difference in TTL in relation to variable tibial drill guide angles because of proximal tibial morphology. They evaluated TTL by measuring the intraosseous length of the guide pin and calculated the mean value in 10 cadaveric specimens. The difference between their results and ours may be due to the difference in the measurement method of the tibial tunnel and the small number of limbs in their study.

This study has some limitations. First, although only the effect of sagittal angle of the TG on aperture widening was evaluated, other factors such as the effect of the starting position of the tibial tunnel were not be evaluated. However, we standardized the starting point to minimize its effect on the outcomes. Second, TW and TTL were measured intraoperatively using a measuring scale or a depth gauge, and inter- and intraobserver variability for measurements was not assessed. Third, although the clinical outcomes were not significantly different among the 3 groups divided based on variation of the sagittal plane angle of the tibial tunnel at the end of 2 year postoperatively, this study did not evaluate any mid- or long-term follow-up differences in clinical outcome among the 3 groups.

## Conclusions

This study shows that the TG set at different angles would affect the severity of intra-articular aperture widening of the tibial tunnel. Setting the TG at 40° significantly reduced the severity of aperture widening during ACL reconstruction using the transtibial technique.

## Conflict of Interest

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

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