Femoral Graft Bending Angle and Femoral Tunnel Geometry of Transportal and Outside-In Techniques in Anterior Cruciate Ligament Reconstruction: An In Vivo 3-Dimensional Computed Tomography Analysis

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Purpose: To compare femoral graft bending angles and femoral tunnel geometries between the transportal (TP) and outside-in (OI) techniques after anatomic double-bundle (DB) anterior cruciate ligament (ACL) reconstruction. **Methods:** Thirty-nine patients underwent DB ACL reconstruction with the TP and OI techniques. They were randomized on the day of surgery to either the TP group (group I, 21 cases) or the OI group (group II, 18 cases). Femoral graft bending angle, femoral tunnel geometry, posterior wall breakage, and tunnel communication were assessed by computed tomography imaging with OsiriX imaging software (Pixmeo, Geneva, Switzerland). **Results:** The mean anteromedial (AM) and posterolateral (PL) femoral graft bending angles of group II (97.3° ± 8.3° and 97.4° ± 8.6°, respectively) were significantly more acute than those of group I (108.2° ± 8.4° and 109.9° ± 8.8°, respectively) ($P < .001$). The mean AM femoral tunnel length of group II (34.3 ± 3.9 mm) was significantly longer than that of group I (31.9 ± 2.7 mm) ($P = .02$). However, the mean PL femoral tunnel lengths did not differ between groups. In 7 cases—4 cases (19.0%) in group I and 3 cases (16.6%) in group II—the femoral tunnel communication was found around the intra-articular aperture. Posterior wall breakage was observed in 5 cases (23.8%), which were all in AM femoral tunnels of group I. **Conclusions:** The OI technique resulted in more acute femoral graft bending angles (difference of 10.9° and 12.5° for AM and PL, respectively) and longer mean AM femoral tunnel lengths (difference of 2.4 mm) than the TP technique after anatomic DB ACL reconstruction, even though these small differences might be unlikely to be of clinical significance. Femoral tunnel communication was found in both groups, and posterior wall breakage was observed in AM femoral tunnels with the TP technique. **Level of Evidence:** Level I, prospective randomized trial.

Arthroscopically assisted anterior cruciate ligament (ACL) reconstruction was originally performed with a 2-incision technique.[1] This technique evolved into an arthroscopic transtibial technique that gained greater popularity. Advances in ACL reconstruction have emphasized the importance of centering the graft within its anatomic insertions.[2,3] However, the transtibial technique may compromise the positioning of the anatomic femoral tunnel because of tibial constraints on femoral drilling.[4,5] Therefore the desire to

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perform independent drilling while creating a femoral tunnel has prompted interest in the transportal (TP) and outside-in (OI) techniques.[6,7]

The TP technique has advantages such as unconstrained tunnel placement and anatomic placement of the femoral tunnel. However, this technique also has disadvantages, such as a short femoral tunnel causing reduced graft length in the tunnel, posterior wall blowout, and poor visual field.[7]

Alternately, the OI technique provides consistent femoral tunnel placement, no posterior wall blowout, a clear visual field, no screw divergence, ease of use for revision ACL reconstruction, and longer tunnel lengths.[8,9] However, this technique has disadvantages including lateral femoral dissection from an additional incision and inconsistent femoral reaming because of variability in the starting position.[10] However, because it uses retractable retrograde cutting bits, such as the FlipCutter (Arthrex, Naples, FL), the technique requires only a portal-sized stab wound rather than a lateral incision and dissection.[10]

Repetitive bending stress on the graft at the femoral tunnel aperture may cause graft damage and tunnel expansion because of the abrasive forces at the contact area on the sharp edge of the bone tunnel aperture.[11-14] Otsubo et al.[15] reported complete or partial rupture in 11% of posterolateral (PL) grafts at the femoral tunnel aperture after an anatomic ACL reconstruction, although they fixed the graft at 20° of knee flexion. Segawa et al.[14] suggested that the femoral tunnel angle was significantly more acute in patients displaying femoral tunnel enlargement than in patients without femoral tunnel enlargement. Some authors have compared the graft bending angles at the femoral tunnel aperture (femoral graft bending angle), which is the angle between the femoral tunnel and graft in the 3-dimensional (3D) plane, between the TT technique and TP technique using virtual simulations in cadavers.[16] In our previous study, we also performed similar in vivo study to compare the femoral graft bending angle between 2 techniques.[17] However, to our knowledge, no randomized, controlled, prospective, in vivo studies have been conducted to compare femoral graft bending angles between the TP and OI techniques.

The purpose of this randomized, controlled, prospective, in vivo study was to compare femoral graft bending angles and femoral tunnel geometries between the TP and OI techniques using 3D computed tomography (CT). Our hypothesis was that the OI technique would result in a longer femoral tunnel length and more acute femoral graft bending angle than the TP technique.

METHODS

Patients

From November 2010 to April 2011, we enrolled 62 patients with a diagnosis of ACL injury. Of the 62 patients, 23 were excluded because of selective bundle reconstruction (2 patients), revision ACL reconstruction (9 patients), multiple ligament injury (6 patients), meniscal allograft transplantation (3 patients), or single-bundle reconstruction for open physis (3 patients). The inclusion criterion was a primary unilateral ACL injury with or without meniscus injury. Thirty-nine patients were ultimately included in this study and were randomly assigned to either the TP technique group (group I, 21 cases) or the retrograde reaming OI technique group (group II, 18 cases) on the day of surgery by permuted block randomization (Fig 1).[18] The sealed envelope was opened in the operating room. There was no significant difference in patient demographics between group I and group II (Table 1).

Institutional review board approval was obtained from our institution before proceeding with this study, and our protocol was also approved. All patients were informed that they were going to participate in a study.

Surgical Techniques

All operations were performed by a single surgeon, who was very experienced in ACL reconstruction using both TP and OI techniques. Portal formation and arthroscopic examinations were conducted in the usual manner. An anteromedial (AM) portal was placed in a slightly more proximal position, with the distal extent of the portal ending at the level of the inferior pole of the patella. An accessory anteromedial (AAM) portal was made approximately 1.5 cm medial from the standard AM portal and just above the medial meniscus anterior horn. The hamstring tendon was harvested. A sextuple (6-stranded) graft, which was composed of triple semitendinosus (for AM bundle) and triple gracilis (for PL bundle), was made for groups I and II. After creation of the femoral tunnel, the femoral tunnel length was measured with a ruler. We then determined the required size of the EndoButton (Smith & Nephew Endoscopy, Andover, MA) for the TP technique and RetroButton (Arthrex) for the OI technique.

TP Anatomic Double-Bundle Reconstruction: The arthroscope was inserted through the AM viewing portal. After examination of the rupture patterns of the

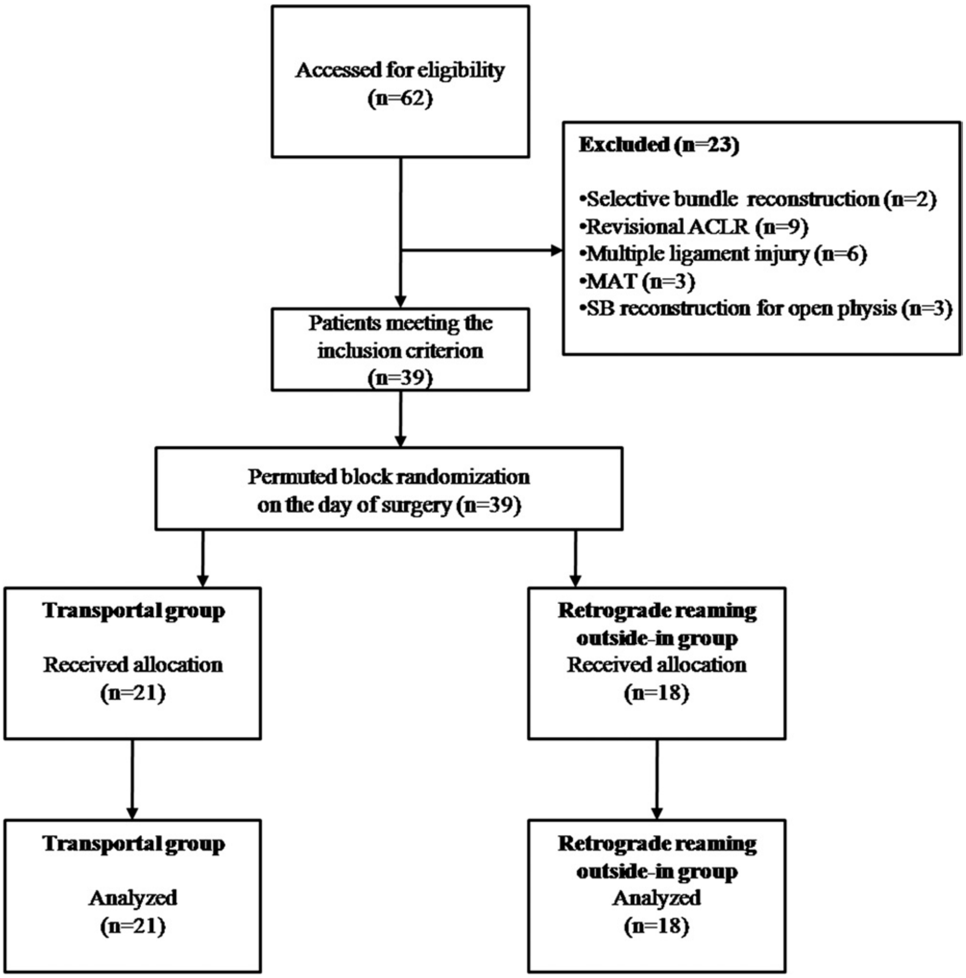

FIGURE 1. Patient flowchart. (ACLR, anterior cruciate ligament reconstruction; MAT, meniscal allograft transplantation; SB, single bundle.)

ACL, the femoral footprints of both the AM and PL bundles were carefully defined with reference to soft-tissue remnants and bony anatomy[19] and marked with a thermal device (ArthroCare, Sunnyvale, CA) and a curved Steadman awl (ConMed Linvatec, Largo, FL). The center of the AM bundle footprint was 5 to 6 mm anterior (shallow) to the posterior cartilage margin or 2 mm from the posterior bony ridge of the lateral femoral condyle, which we called the "fellow's ridge" because it is located posterior to the lateral intercondylar ridge ("resident's ridge") (Fig 2),[20] and 3 to 4 mm inferior to the posterolateral corner of the intercondylar notch, which was verified at 90° of knee flexion. The center of the PL bundle footprint was positioned 5 mm superior to the edge of the joint cartilage on an imaginary line perpendicular to the

TABLE 1. *Patient Demographics*

	Group I (n = 21)	Group II (n = 18)	*P* Value
Age (yr)	36.7 ± 10.3 (18-47)	30.0 ± 12.2 (17-54)	.07
Sex (n): M/F	18/3	14/4	.68
BMI (kg/m^2)	24.6 ± 3.7 (20.7-26.4)	25.3 ± 4.1 (20.8-27.7)	.57
Time from injury to reconstruction (mo)	6.7 ± 4.8 (0.75-24)	7.4 ± 38.6 (0.75-24)	.47
Preoperative maximum flexion angle (°)	127.7 ± 10.2 (90-140)	131.5 ± 10.9 (118-140)	.31

NOTE. Data are expressed as mean ± SD (range) except for sex.
Abbreviations: BMI, body mass index; F, female; M, male.

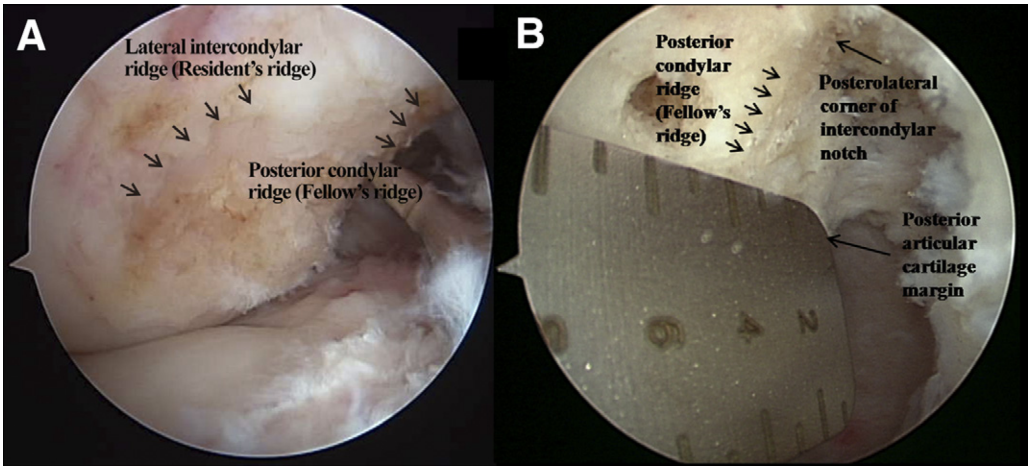

FIGURE 2. AM bundle footprint during ACL reconstruction using TP technique. (A) The centers of the femoral AM footprints were marked with a curved Steadman awl. (B) The center of the AM bundle footprint was positioned according to the soft-tissue and bony landmarks.

tangent at the lowermost portion of the lateral femoral condyle at 90° of knee flexion.[21] A Bullseye femoral guide (ConMed Linvatec) was inserted through the AAM portal, and a 3.2-mm guide pin was inserted through the Bullseye guide with the tip aimed at the center of the AM bundle femoral insertion site that was previously defined at 90° of knee flexion. A Sentinel cannulated reamer (ConMed Linvatec) was introduced over the guide pin and flexed maximally. We drilled to a depth of 27 mm, which enabled graft length in the femoral tunnel of 20 mm and EndoButton flipping outside of the femoral tunnel. A 4.5-mm EndoButton drill bit (Smith & Nephew Endoscopy) was drilled out through the lateral cortex. The PL femoral tunnel was then made through same procedure.

The anatomic tibial insertion sites of both bundles were marked with an ArthroCare device, 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 bases of the AM/PL tibial insertion sites. The AM and PL tibial tunnels were then drilled with a cannulated drill. An EndoButton CL (Smith & Nephew Endoscopy) was used for femoral fixation, and a bioabsorbable interference screw was used for tibial fixation in a 0° of knee flexion state.

OI Anatomic Double-Bundle Reconstruction Using FlipCutter: A central midpatellar portal was made at the patellar tendon to introduce the RetroConstruction Drill guide (Arthrex) after we marked the point of entry with an ArthroCare device and a curved Steadman awl on the center of the AM and PL footprint, which was made using the same landmarks as in the TP technique. An ACL femoral guide (Arthrex) was then placed through the central midpatellar portal. The center of the guide tip was aimed at the footprint center that was marked previously. The guide angle was set at 110° for the AM femoral tunnel and 100° for the PL femoral tunnel. However, we did not determine the angle of the guide in the axial plane of the femur and only held the femoral drill guide slightly in the anterior-to-posterior direction in the axial plane of the femur. A stab incision was made at the point where the FlipCutter drill sleeve (Arthrex) contacted skin. To prevent femoral tunnel inaccuracy due to deflection, we held and maintained the femoral guide while making the femoral tunnel. In addition, to prevent slippage of the drill sleeve from the femoral guide, we held and fixed the drill sleeve using a Kelly clamp (Fig 3). We drilled the FlipCutter into the joint slowly with steady pressure through a stab incision over the lateral femoral condyle and tapped the 7-mm drill sleeve tip into the bone lightly. The blue hub of the FlipCutter was turned counterclockwise to loosen the blade positioned at the tip, and the blade was then turned 90° into the cutting position with a probe; the blade was locked by turning the blue hub clockwise (Fig 4). Forward drilling was continued to a depth of 27 mm with retrograde force. The FlipCutter was removed after loosening the blade. A tibial tunnel was made, as in the TP group. The AM and PL grafts were passed through the tunnel, and the RetroButton was flipped to establish femoral fixation. The grafts were tensioned, and the PL and AM grafts were fixed to 0°

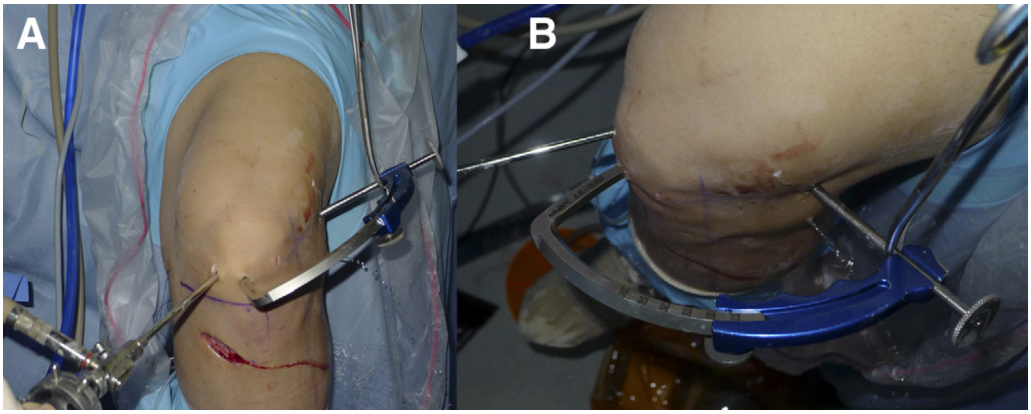

FIGURE 3. Femoral tunnel drilling using OI technique with FlipCutter. (A) The FlipCutter guide was inserted through the central midpatellar portal, and the guide sleeve was oriented in the anterior-to-posterior direction on the axial plane. (B) The FlipCutter guide angle was set at 110° for AM femoral tunnel drilling and 100° for PL femoral tunnel drilling.

of knee flexion at the tibial tunnel with bioabsorbable interference screws.

CT Protocol and Measurement

CT scans were performed on all knees after ACL reconstruction. Patient consent was obtained preoperatively. A CT scanner (LightSpeed VCT [volume CT]; GE Medical Systems, Milwaukee, WI) 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 extraction of Digital Imaging and Communications in Medicine (DICOM) data from the picture archiving and communication system, it was imported into OsiriX imaging software (version 3.8; Pixmeo, Geneva, Switzerland). OsiriX is free DICOM software that is used widely in clinical and research fields with comparable efficacy and reliability to commercially available software.[22]

To measure femoral tunnel position, DICOM data were imported to OsiriX to create a 3D model of the distal femur. Initially, the distal femur model was positioned horizontally in the "strict lateral position," where the femoral condyles were superimposed as described by Bernard et al.[23] for the lateral radiograph of the knee. The model was then rotated to a distal view, and the medial femoral condyle was virtually removed at the highest point of the anterior aperture of the intercondylar notch, leaving the lateral femoral condyle. Finally, the model was rotated back to the

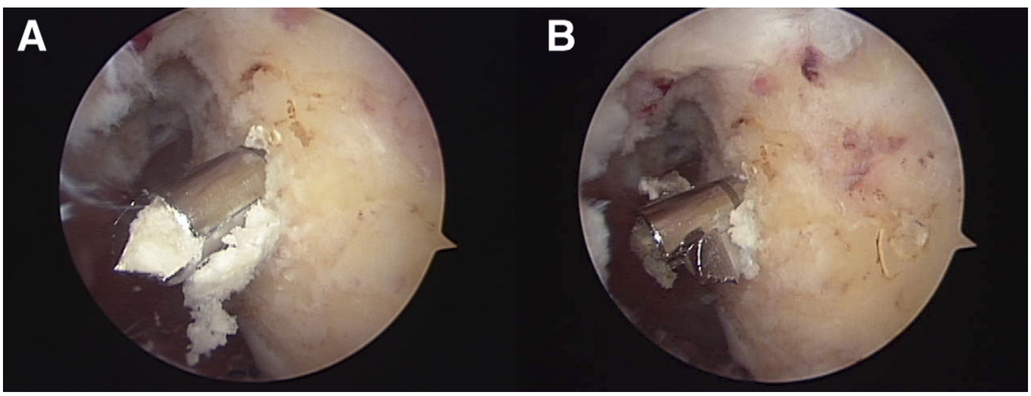

FIGURE 4. Femoral tunnel drilling using OI technique with FlipCutter. (A) The FlipCutter was drilled into the joint through a small incision over the lateral femoral condyle. (B) After loosening the blade positioned at the tip of the FlipCutter, we turned the blade 90° into the cutting position using a probe and locked the blade.

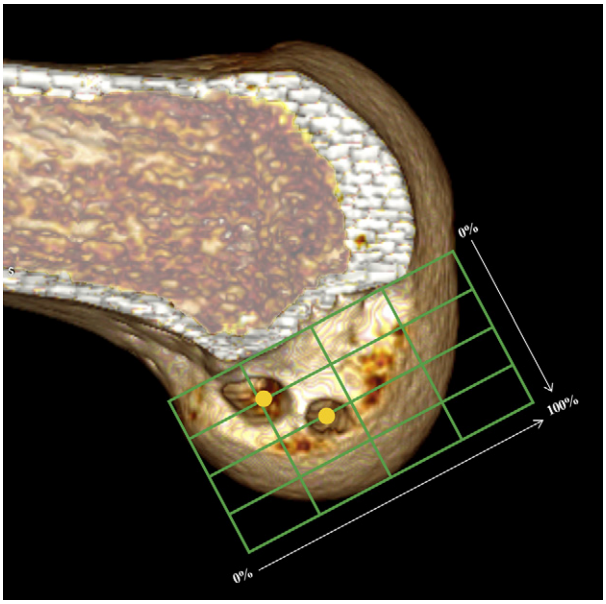

Figure 5. A view of the lateral femoral condyle in a strictly lateral position was obtained from the 3D model using OsiriX imaging software. The locations of the tunnels were quantified and presented as the percentage distance from the deepest subchondral contour and the intercondylar notch roof to the center of the tunnel by use of the Bernard quadrant method.

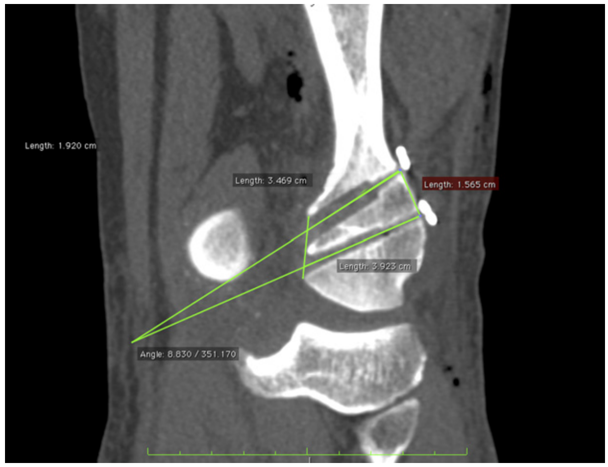

Figure 7. To measure the femoral tunnel lengths, the plane in which the entire length of the femoral tunnel showed maximum width was selected by use of OsiriX imaging software. The femoral tunnel length, the divergent angle between the AM and PL femoral tunnel, and the extra-articular aperture distance were measured.

strict lateral position. The location of the tunnels was quantified and presented as the percentage distance from the deepest subchondral contour and the intercondylar notch roof to the center of the tunnel (Fig 5).

The femoral 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 were viewed together, was selected to measure the femoral graft bending angle (Fig 6).[17] To measure the divergence of the femoral tunnel angle and extra-articular tunnel aperture distance of the AM and PL femoral tunnels (extra-articular aperture distance), we measured the angles between the lines passing through the center of each tunnel and measured the distances between the extra-articular apertures. The plane in which the entire length of the femoral tunnel showed the maximum width was selected to measure the femoral tunnel length. The distance between the centers of the intra- and extra-articular tunnel apertures was measured (Fig 7). We also evaluated AM and PL fem-

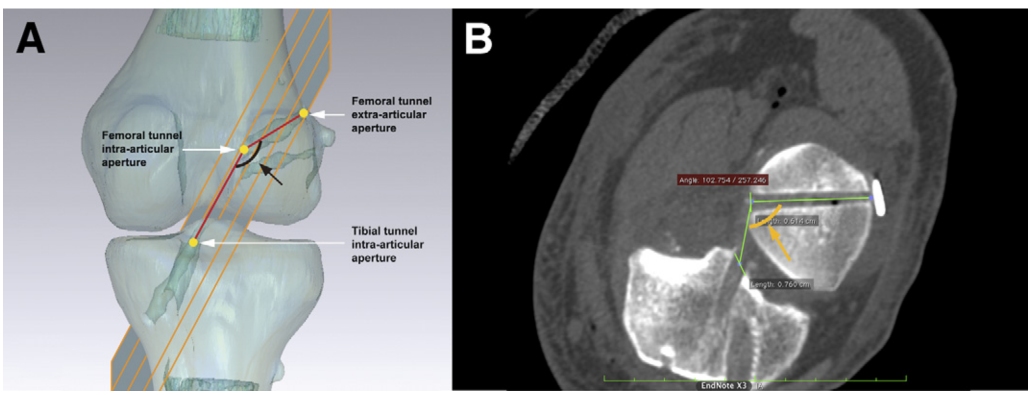

Figure 6. (A) Plane for measuring graft bending angle viewed from anteroposterior direction of knee. We obtained the plane in which the centers of the extra- and intra-articular apertures of the femoral tunnel and the center of the intra-articular aperture of the tibial tunnel were shown together and measured the femoral graft bending angle (black arrow). (B) OsiriX image viewed from perpendicular direction to plane for measuring femoral graft bending angle and measurement of femoral graft bending angle (arrow).

Table 2. *Results of Intraclass Correlation Coefficient (ICC) Value of Each Measurement*

	Femoral Tunnel Position				Femoral Graft Bending Angle		Femoral Tunnel Length		Femoral Tunnel Divergent Angle	Extra-Articular Aperture Distance
	Horizontal Position of AM	Vertical Position of AM	Horizontal Position of PL	Vertical Position of PL	AM	PL	AM	PL		
Intertester										
ICC	0.832	0.856	0.845	0.867	0.849	0.868	0.997	0.978	0.883	0.867
Minimum ICC	0.802	0.812	0.816	0.823	0.827	0.841	0.988	0.956	0.846	0.832
Maximum ICC	0.876	0.889	0.889	0.899	0.898	0.911	0.999	0.994	0.932	0.923
Tester 1										
ICC	0.862	0.886	0.878	0.891	0.819	0.891	0.998	0.997	0.854	0.843
Minimum ICC	0.824	0.832	0.831	0.854	0.802	0.879	0.990	0.988	0.824	0.818
Maximum ICC	0.899	0.923	0.901	0.919	0.879	0.935	0.999	0.999	0.889	0.879
Tester 2										
ICC	0.853	0.874	0.864	0.884	0.879	0.926	0.995	0.992	0.843	0.835
Minimum ICC	0.821	0.832	0.831	0.847	0.864	0.901	0.989	0.983	0.812	0.801
Maximum ICC	0.882	0.912	0.908	0.917	0.964	0.988	0.999	0.999	0.876	0.868

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

oral tunnel communication at the intra-articular aperture and posterior wall breakage of the femoral tunnel.

Reliability and Statistical Analysis

Two orthopaedic surgeons (independent observers) developed and agreed to the measurement methods together. However, they were blinded to each other's measurements and were blinded to their own prior measurements. 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 intraobserver and interobserver reliability with the intraclass correlation coefficient. A priori power analysis was performed to determine the sample size by use of the 2-sided hypothesis test at an α level of .05 and a power of 0.8. The result of our study involving 21 and 18 cases indicated adequate power to detect a significant difference in femoral graft bending angle and tunnel length between the 2 groups (0.99 and 0.86, respectively), which was the primary outcome measure in this study.

The results of the 2 groups were compared by use of 2-sample t tests and Wilcoxon rank sum tests for femoral tunnel position, the graft bending angle, and femoral tunnel geometry. Significance was set at $P \leq .05$. Statistical analysis was performed with SPSS software (version 12.0; SPSS, Chicago, IL).

RESULTS

The interobserver reliability and intraobserver reliability ranged from 0.83 to 0.98 and 0.85 to 0.98, respectively (Table 2).

Femoral Tunnel Position

There was no significant difference in AM/PL femoral tunnel position except for PL femoral tunnel position perpendicular to the Blumensaat line ($P = .007$) (Table 3).

Femoral Graft Bending Angle, Femoral Tunnel Divergent Angle, and Extra-Articular Aperture Distance

The mean femoral graft bending angles of the AM and PL tunnels in group II were significantly more acute than those of group I ($P < .001$). The difference in mean femoral graft bending angle between the TP and OI techniques was 10.9° for AM and 12.5° for PL. The mean femoral tunnel divergent angle of group I was larger than that of group II, although the difference was not significant ($P = .06$). The mean extra-articular aperture distance of group I was longer than that of group II, although the difference was not significant ($P = .26$) (Table 4).

Table 3. *Femoral Tunnel Positions of AM and PL Femoral Tunnels*

	Group I (n = 21)	Group II (n = 18)	*P* Value
Parallel to Blumensaat line (%)			
AM	23.9 ± 5.2 (8-31)	24.2 ± 4.2 (17-31)	.87
PL	34.7 ± 5.9 (26-49)	37.4 ± 5.6 (29-47)	.17
Perpendicular to Blumensaat line (%)			
AM	22.5 ± 8.8 (10-36)	26.5 ± 7.1 (16-43)	.12
PL	51.0 ± 5.1 (42-62)	56.6 ± 6.6 (41-69)	.007

NOTE. Data are expressed as mean ± SD (range).

Tunnel Length

The mean AM femoral tunnel length of group II was significantly longer than that of group I ($P = .02$) (Table 5). The mean PL femoral tunnel length of group II was longer than that of group I, although the difference was not significant ($P = .24$). The difference in mean femoral length between the TP and OI techniques was 2.4 mm for AM and 1.6 mm for PL. The number of cases with a femoral tunnel length of less than 30 mm for the AM and PL tunnels in group I was 4 (19.0%) and 3 (14.3%), respectively, and in group II, the number of cases was 3 (16.7%) and 2 (11.1%), respectively. However, there were no cases with a femoral tunnel length of less than 25 mm.

Femoral Tunnel Communication and Posterior Wall Breakage

In 7 cases—4 (19.0%) in group I and 3 (16.6%) in group II—the femoral tunnel communication was found around the intra-articular aperture. Posterior wall breakage was observed in 5 cases (23.8%), which were all in AM femoral tunnels of group I (Fig 8).

DISCUSSION

The principal findings of this prospective, randomized, comparative, in vivo study were that the OI technique resulted in a longer femoral tunnel length (AM femoral tunnel) and a more acute femoral graft bending angle than the TP technique. To our knowledge, this is the first in vivo study to compare the femoral graft bending angles and femoral tunnel geometry between the TP and OI techniques.

Many studies presented femoral tunnel position in anatomic double-bundle (DB) ACL reconstruction.[24-27] In our study the AM femoral tunnel position of the TP and OI techniques was 23.9% ± 5.2% and 24.2% ± 4.2%, respectively, for a position parallel to the Blumensaat line and 22.5% ± 8.8% and 26.5% ± 7.1%, respectively, for a position perpendicular to the Blumensaat line. These results were similar to those in the study of Colombet et al.[25] The PL femoral tunnel position of the TP and OI techniques was 34.7% ± 5.9% and 37.4% ± 5.6%, respectively, for a position parallel to the Blumensaat line and 51.0% ± 5.1% and 56.6% ± 6.6%, respectively, for a position perpendicular to the Blumensaat line. These results were similar to those in the study of Forsythe et al.[24] In addition, the AM/PL femoral tunnel positions in our study were slightly similar to the mean centers of the AM/PL ACL bundle represented in a recent systematic review of the ACL femoral footprint, which were 21.5%/23.1% for the AM bundle and 32%/48.8% for the PL bundle.[27] In our study there was no

Table 4. *Comparison of Femoral Graft Bending Angle, Femoral Tunnel Divergent Angle, and Extra-Articular Aperture Distance Between Group I (TP Technique) and Group II (OI Technique)*

	Group I	Group II	*P* Value
Femoral graft bending angle (°)			
AM	108.2 ± 8.4 (95.9-121.5)	97.3 ± 8.3 (86.1-120.3)	<.001
PL	109.9 ± 8.8 (92.7-123.3)	97.4 ± 8.6 (82.3-112.4)	<.001
Femoral tunnel divergent angle (°)	10.6 ± 3.2 (2.8-17.0)	7.4 ± 6.7 (4.16-26.5)	.06
Femoral tunnel extra-articular aperture distance (mm)	14.9 ± 2.4 (10.8-19.4)	13.8 ± 3.4 (6.6-20.3)	.26

NOTE. Data are expressed as mean ± SD (range).

Table 5. *Tunnel Lengths in Group I (TP Technique) and Group II (OI Technique)*

	Tunnel Length (mm)		
Femur	Group I	Group II	*P* Value
AM	31.9 ± 2.7 (27.0-41.9)	34.3 ± 3.9 (27.3-37.9)	.02
PL	34.0 ± 3.9 (26.0-42.1)	35.6 ± 4.4 (28.0-40.8)	.24

NOTE. Data are expressed as mean ± SD (range).

significant difference in femoral tunnel position between the TP and OI techniques, except for only PL femoral tunnel position perpendicular to the Blumensaat line. Because we made the femoral tunnel at an anatomic position with reference to consistent anatomic landmarks using both techniques, we assumed that the difference in femoral tunnel positions between the 2 techniques and error caused by the different tunnel positions would not be much in our study. It is necessary to evaluate more cases comparing femoral tunnel positions between the TP and OI techniques.

The repetitive bending stress on the graft at the femoral tunnel aperture is believed to be responsible for graft damage, due to the abrasive forces at the contact area on the sharp edge of the bone tunnel aperture when the graft is acutely bent and stretched.[11-14] Otsubo et al.[15] reported that complete or partial ruptures were observed in 11% of PL grafts at the femoral tunnel aperture in arthroscopic evaluations performed after anatomic DB ACL reconstruction using the TP technique.

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.[10] However, they did not consider the angular change in the femoral tunnel according to the knee flexion angle. Some authors recommended 110° of flexion when drilling the AM tunnel through the AM portal.[6,28] Basdekis et al.,[6,29] with regard to the AM and PL tunnel orientation, suggested that 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.[6] In our study a femoral tunnel was drilled through the AAM portal after the knee was flexed to the maximum degree. However, our results showed that the femoral graft bending angle is more acute when using the OI technique than when using the TP technique.

Several studies have been performed to compare femoral tunnel directions between the TT and OI techniques. The femoral tunnel direction of the OI technique was more horizontal than that of the TT technique, in both the frontal and sagittal planes.[8,30] However, only 1 study compared the femoral tunnel directions of the TP and OI techniques. On lateral radiographs, the angles between the axis of the femoral tunnel and Blumensaat line in the TT, TP, and OI techniques were not significantly different. However, on anteroposterior radiographs, significant differences among the 3 techniques were found in the angulation of the femoral tunnel, and the femoral tunnel angulation of the OI technique was most horizontal in the

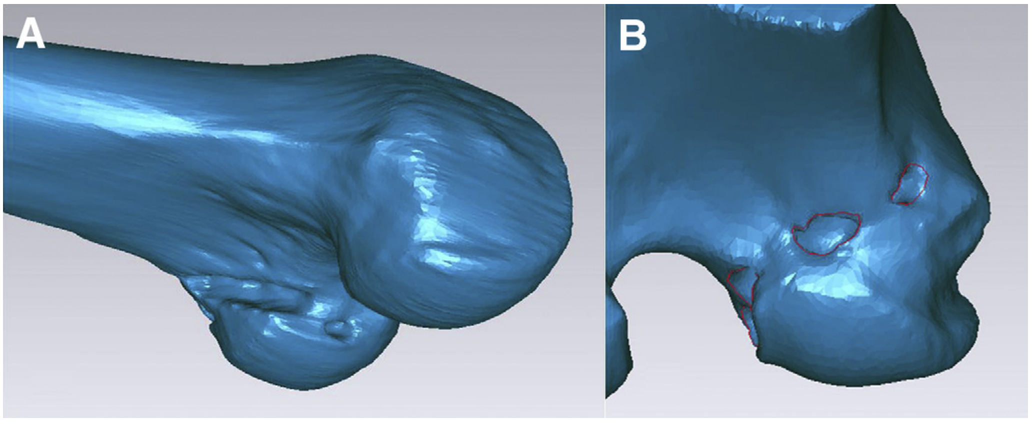

Figure 8. Posterior wall blowout after ACL reconstruction with TP technique. (A) Whole posterior wall blowout. (B) Middle of femoral tunnel blowout.

coronal plane.[31] Therefore the horizontal femoral tunnel direction in the OI technique may cause the more acute femoral graft bending angle. However, as far as we are aware, there is no study to show clinical results comparing sharp and blunt graft bending angles in ACL reconstruction. In the present study, the difference in mean femoral graft bending angle between the TP and OI techniques was relatively small, and we did not compare clinical results between the 2 groups. Therefore we could not conclude that the OI technique would show poor clinical results compared with the TP technique because of a small difference in mean graft bending angle, even though there was a significant difference in femoral graft bending angle between the 2 groups. However, in group II the minimum graft bending angle of AM/PL was 86.1° and 82.3°, respectively, and the maximum difference in AM/PL femoral graft bending angle between the TP and OI techniques was 35.4° and 41.0°, respectively (maximum femoral graft bending angle of TP technique minus minimum femoral graft bending angle of OI technique). Therefore, in such cases, possibly, the difference in femoral graft bending angle between the TP and OI techniques might be clinically significant.

In the TP technique, the femoral tunnel drilling angle is constrained because of the combination of knee hyperflexion and the portal fixed position just above the medial meniscus and lateral to the medial femoral condyle articular cartilage.[7] Therefore femoral tunnel obliquity in the coronal and axial planes of the distal femur might be difficult to modify with the TP technique. However, the femoral starting point and drilling angle are arbitrary in the OI technique. This might be the cause of the wider range of standard deviations for the femoral tunnel length in group II than those of group I in our study. Lubowitz and Konicek[10] suggested that more specific dissection of the lateral femoral epicondylar area would be necessary to standardize the anatomic starting position of the OI pin on the femur and that this might reduce variability in outcomes. They made the femoral tunnel through a stab incision at the distal midlateral femoral metaphyseal flare, 4 cm proximal to the lateral epicondyle, using the guide set at 110°.[10] In our technique the FlipCutter guide angle was set at 100° for the PL femoral tunnel and 110° for the AM femoral tunnel. However, we did not determine the angle of the guide in the axial plane. To prevent an acute femoral graft bending angle, it would be necessary to create a femoral tunnel direction that was more proximal to distal in the coronal plane and more horizontal in the axial plane perpendicular to the femoral shaft axis. If the femoral tunnel is drilled in a more vertical direction (anterior-to-posterior direction) in the axial plane of the distal femur and a less oblique direction (proximal to distal) in the coronal plane of the distal femur, this change in drilling angle may cause a more acute femoral graft bending angle and more elliptic intra-articular aperture, which may lead to graft toggle. The guide angle ranged from 90° to 120° for the FlipCutter. Therefore it would be preferred to increase the guide angle as far as the guide permits and to lower the guide for the horizontal direction in the axial plane. In addition, it would be necessary to standardize the anatomic landmarks of the lateral femur to reduce variability in outcomes.

In our study the AM and PL femoral tunnels showed divergent angles for both the TP and OI techniques. In DB ACL reconstruction, prevention of femoral tunnel convergence is imperative for separate graft tunnel function.[32] Convergence of the tunnel may cause tunnel communication,[33] which jeopardizes graft function and knee stability; revision surgery is often necessary and difficult.[32] In the TP technique, Hantes et al.[33] showed that the bony bridge between the AM and PL femoral tunnels was triangular. In our study there was no case with tunnel convergence. However, in 7 cases femoral tunnel communications were found around the intra-articular aperture; this occurred in cases treated with both the TP and OI techniques. The reasons for femoral tunnel communication at the intra-articular aperture were that the 2 tunnels were too close to each other for a small ACL footprint size and that the femoral tunnel diameter was too large compared with the ACL femoral footprint size. Pombo et al.[34] suggested that DB reconstruction can present a challenge when a patient has an insertion site smaller than 14 mm in diameter. Therefore, in cases with a small ACL footprint, it is preferable to consider single-bundle reconstruction to prevent intra-articular tunnel communication. Some authors reported that the use of anatomic aimers, which make the thickness of the bone bridge between the intra-articular apertures of the 2 tunnels 2 to 3 mm and the distance between the centers of the 2 tunnels consistently 8 to 9 mm, helped to avoid a bone bridge fracture and tunnel communication.[33]

The mean AM femoral tunnel length of the TP technique was significantly shorter than that of the OI technique. However, the mean PL femoral tunnel length was not significantly different between the 2 groups. The reported risk of the TP technique for ACL femoral tunnel creation was a short tunnel length.[4] Chang et al.[35] suggested that the femoral tunnel made with the TP technique would be placed more horizontally within the femur, which reduces the tunnel length, and found that a femoral tunnel made by the TP technique was shorter than that made by the TT technique. Moreover, in the TP technique, the tunnel length decreased according to the knee flexion angle. Basdekis et al.[6] observed a significantly shorter AM femoral tunnel length at knee flexion of 90° compared with 110°, 130°, and maximum flexion (27.1 mm at 90° of flexion, 38.9 mm at 110° of flexion, 38.8 mm at 130° of flexion, and 39.2 mm at maximum flexion).

Lubowitz and Konicek[10] compared the AM femoral tunnel length between the TP and OI techniques. The mean AM femoral tunnel length of the OI technique was significantly longer than that of the TP technique. The mean difference in femoral tunnel length between the TP and OI techniques was 3.6 mm in their study.[10] However, in our study the difference in mean femoral length between the TP and OI techniques was 2.4 mm for AM and 1.6 mm for PL. The cause of this result might be that they used an offset femoral guide. Bedi et al.[36] suggested that referencing of the posterior wall with an offset guide when drilling through the AM portal may paradoxically increase the posterior trajectory of the guidewire, thereby increasing the risk of short tunnels. This might make the mean difference in our study smaller than that in the study by Lubowitz and Konicek. Both the TP and OI techniques can be used to make an oblique femoral tunnel at the anatomic ACL footprint.[7] Even though our result showed a significant difference in AM femoral tunnel length, such a small difference would be unlikely to be clinically significant. However, in the OI technique, manipulation of the drill angle and starting position can be used to change the femoral tunnel length and direction.[10] Therefore it is necessary to determine the drill angle and starting position when using the OI technique, as we discussed earlier.

Short tunnels can result in reduced graft lengths within the femoral tunnel.[37] In this study, button systems (EndoButton for TP technique and RetroButton for OI technique) were used for femoral fixation of the graft. There is little evidence available to determine whether graft length in the tunnels of less than 15 mm can be safely used in ACL reconstruction, particularly for humans.[37,38] The numbers of cases with femoral tunnel lengths of less than 30 mm for the AM and PL tunnels in group I were 4 and 3, respectively, and in group II, they were 3 and 2, respectively. The traditional cortical suspensory fixation device diminishes the graft length in the tunnel, which can make tunnel dead space not occupied by the graft. The minimal loop length of the EndoButton CL system and RetroButton system was 15 mm. If the tunnel length was less than 30 mm, the graft length in the tunnel would be less than 15 mm, which may compromise the healing process.[37,38] Recently, newer-generation adjustable suture loop suspensory fixation devices, such as EndoButton Direct (Smith & Nephew), were introduced and could increase the graft length in the tunnel without tunnel dead space. Therefore the EndoButton Direct system was used in cases with femoral tunnel length of less than 30 mm, which enabled an adequate graft length in a tunnel greater than 15 mm. However, we used the EndoButton Direct in only 2 cases operated on by the TP technique because of mismatches between the intraoperative measurements and postoperative CT measurements of the femoral tunnel length. The RetroButton system does not include a device to compensate for femoral tunnel length of less than 30 mm. Therefore, when femoral tunnel lengths are less than 30 mm, the graft length in the tunnel would be less than 15 mm if we used the RetroButton system.

Knee hyperflexion is required when reaming the femoral tunnel through the AM portal to avoid posterior wall breakage.[7] In our study, posterior wall breakage in the AM femoral tunnel was found in 5 cases (23.8%) using the TP technique, even though the femoral tunnel was made with the knee in the fully flexed position. Bedi et al.[36] reported that 19.4% of femoral tunnels made by the TP technique using an offset guide showed posterior wall breakage. However, as far as we were aware, no in vivo study has described the rates of posterior wall breakage with the TP technique. Our incidence of posterior wall breakage was relatively high and might be caused by a kind of technical error, because the femoral tunnel might be too close to the posterior condylar margin. It is often difficult to differentiate broken walls from intact walls intraoperatively. Therefore it is better to check the posterior wall by probing areas suspicious for posterior wall breakage.

There are several limitations of this study. First, we could not compare clinical results and second-look arthroscopic findings between the TP and OI techniques. Therefore we could not provide some form of justification of superiority of the 2 techniques for the relatively small differences in graft bending angle and tunnel length as to whether there would be a clinical consequence of these differences. However, interest in the graft bending angle after ACL reconstruction has developed recently, and as far as we are aware, there is no study to compare femoral graft bending angle between the TP and OI techniques. Comparing clinical results between the 2 techniques will be performed in our next study. Second, the femoral graft bending angle was not evaluated for various degrees of knee flexion but was evaluated only with the knee extended. Many authors have suggested that the AM and PL bundles are at their greatest lengths at full extension, and therefore tension is the greatest in this position.[16,39] Therefore obtaining the 3D CT scan in an extended-knee position is very informative. Third, we were not able to standardize starting position according to anatomic landmarks of the lateral femur in making the femoral tunnel using the OI technique. In our study we only set the femoral guide angle at 110° for the AM femoral tunnel and 100° for the PL femoral tunnel and the drilling angle at slightly superior angulation in the axial plane by use of the OI technique. If we used anatomic landmarks for the starting position in making the femoral tunnel using the OI technique, a more consistent femoral graft bending angle and femoral tunnel length could be made. It would be necessary to standardize the anatomic landmarks in making the femoral tunnel using the OI technique.

CONCLUSIONS

The OI technique resulted in more acute femoral graft bending angles (difference of 10.9° and 12.5° for AM and PL, respectively) and longer mean AM femoral tunnel lengths (difference of 2.4 mm) than the TP technique after anatomic DB ACL reconstruction, even though these small differences might be unlikely to be of clinical significance. Femoral tunnel communication was found in both groups, and posterior wall breakage was observed in AM femoral tunnels with the TP technique.

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