Comparison of Femoral Tunnel Geometry, Using In Vivo 3-Dimensional Computed Tomography, During Transportal and Outside-In Single-Bundle Anterior Cruciate Ligament Reconstruction Techniques

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Purpose: To compare the transportal (TP) and outside-in (OI) techniques regarding femoral tunnel position and geometry after anatomic single-bundle (SB) anterior cruciate ligament (ACL) reconstruction. **Methods:** This study included 51 patients who underwent anatomic SB ACL reconstruction with the TP (n = 21) or OI (n = 30) technique. All patients underwent 3-dimensional computed tomography 3 days after the operation. The femoral tunnel position (quadrant method), femoral graft bending angle, femoral tunnel length, and posterior wall breakage were assessed by immediate postoperative 3-dimensional computed tomography with OsiriX imaging software. **Results:** The OI technique had a shallower femoral tunnel position (arthroscopic position) than did the TP technique (P = .005). The mean femoral graft bending angle was significantly more acute with the OI technique (101.3° ± 8.2°) than with the TP technique (107.9° ± 10.0°) (P = .02). The mean femoral tunnel length was significantly greater with the OI technique (33.0 ± 3.5 mm) than with the TP technique (29.6 ± 3.9 mm) (P = .003). Posterior wall breakage occurred in 7 cases (33.3%) with the TP technique and 1 case (3.3%) with the OI technique (P = .02). **Conclusions:** The mean femoral tunnel position was significantly shallower (arthroscopic position) with the OI technique than with the TP technique. The OI technique resulted in a more acute femoral graft bending angle, longer femoral tunnel length, and lower incidence of posterior wall breakage than did the TP technique. These results might be helpful for anatomic SB ACL reconstruction using TP and OI techniques. **Level of Evidence:** Level III, retrospective comparative study.

Recently, interest in anatomic anterior cruciate ligament (ACL) reconstruction has increased. Anatomic ACL reconstruction maintains the normal kinematics of the knee and may reduce the risk of osteoarthritis developing over the long-term.[1,2] In addition, biomechanical studies have found that anatomic reconstruction more closely re-creates normal biomechanics than does nonanatomic reconstruction,[3,4] and clinical studies also have confirmed the importance of anatomic reconstruction.[5,6] In ACL reconstruction the femoral tunnel is more important to anatomic reconstruction than is the tibial tunnel.[7] Three techniques for creating the femoral tunnel during anatomic ACL reconstruction include transtibial, transportal (TP), and outside-in (OI) techniques.

Conventional transtibial techniques make it difficult to position the femoral tunnel anatomically because of tibial constraint.[8,9] Therefore the TP and OI techniques have received much attention because they offer the possibility of independent drilling to create an anatomic femoral tunnel.[10] However, TP technique has disadvantages, such as a short femoral tunnel, posterior wall breakage, and a poor visual field.[10] In contrast, the OI technique does not cause posterior wall breakage and has a clear visual field and longer tunnel length; however, lateral femoral dissection and inconsistent femoral drilling are disadvantages.[11,12]

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Table 1. Patient Demographic Data

	TP Group (n = 21)	OI Group (n = 30)	*P* Value
Age, yr	33.0 ± 13.3 (15-53)	30.7 ± 13.3 (13-52)	.51
Sex, M/F, n	12/9	24/6	.07
BMI, kg/m^2	23.9 ± 3.5 (20.5-25.4)	24.1 ± 4.4 (20.1-28.9)	.54
Direction, right/left, n	13/8	22/8	.38
Time from injury to reconstruction, months	6.4 ± 4.2 (0.75-24)	7.3 ± 40.5 (0.75-24)	.54
Preoperative maximum flexion angle, °	127.5 ± 9.1 (90-140)	131.4 ± 10.3 (118-140)	.49

NOTE. Data are expressed as mean ± SD (range) unless otherwise indicated.
BMI, body mass index; F, female; M, male.

The TP or OI technique for anatomic ACL reconstruction could change the femoral tunnel geometry or tunnel position.[13] The femoral graft bending angle, defined as the angle between the graft and the femoral tunnel,[14] could affect the repetitive bending stress on the graft at the femoral tunnel aperture, which could cause graft damage or tunnel expansion due to abrasive forces on the edge of the femoral tunnel aperture.[15-17] The femoral tunnel length affects the graft length in the femoral tunnel if a suspensory fixation system is used for femoral graft fixation during ACL reconstruction.[18] Therefore, if the femoral tunnel geometry (femoral graft bending angle and femoral tunnel length) differs between the TP and OI techniques, it is possible that the clinical result may also differ, even though both techniques allow the creation of an anatomic femoral tunnel.

A number of recent studies have analyzed the femoral tunnel geometry or tunnel position associated with these techniques.[13,14,19-23] However, to our knowledge, no studies have evaluated both the femoral tunnel position and femoral tunnel geometry using 3-dimensional (3D) computed tomography (CT) after anatomic single-bundle (SB) ACL reconstruction with the TP or OI technique. Thus the purpose of our study was to compare the TP and OI techniques in terms of the femoral tunnel position and femoral tunnel geometry after anatomic SB ACL reconstruction. The hypotheses of our study were that the femoral tunnel made by the OI technique would show a more acute femoral graft bending angle and longer femoral tunnel length and that the femoral tunnel position would be different between the 2 groups, although both techniques could make the femoral tunnel anatomically.

Methods

Between March 2011 and March 2014, 54 consecutive patients underwent ACL reconstruction with tibialis anterior allograft. We retrospectively reviewed medical records and 3D CT images of these patients. The inclusion criterion was isolated primary SB ACL injury with or without meniscus injury. The exclusion criteria were revision ACL reconstruction, a combined additional ligament injury, and double-bundle ACL reconstruction. Three patients were excluded because of revision ACL reconstruction (2 cases) or double-bundle ACL reconstruction (1 case). A total of 51 cases were included in this study. Twenty-one patients underwent anatomic SB ACL reconstruction with the TP technique between March 2011 and July 2012 (TP group). Thirty patients underwent anatomic SB ACL reconstruction with the OI technique between July 2012 and March 2014 (OI group). All operations were performed by a single surgeon (J.G.K.) who has experience with these techniques. Institutional review board approval was obtained from our institution before proceeding with this study, and our protocol was also approved. There was no significant difference in demographic data between the 2 groups (Table 1). The mean follow-up period of the 51 cases was 9.2 ± 6.3 months (range, 0.5 to 47 months). The mean follow-up period was 13.8 ± 9.6 months (range, 3 to 47 months) for the TP group and 7.5 ± 5.6 months (range, 0.5 to 21 months) for the OI group.

Surgical Technique

Standard portal formation and arthroscopic examinations were conducted, and we created an additional accessory anteromedial portal located 1.5 cm medial to the anteromedial (AM) portal just above the medial meniscus. Tibialis anterior allograft of an appropriate size was used according to the size of the ACL femoral footprint and intercondylar notch to prevent graft impingement on the intercondylar notch or posterior cruciate ligament (7 to 10 mm). The mean tunnel diameter was 8.6 ± 0.7 mm (range, 7 to 10 mm) in the TP group and 9.0 ± 0.5 mm (range, 8 to 10 mm) in the OI group (P = .08). The center of the AM bundle footprint was 6 to 7 mm distal (shallow) to the posterior cartilage margin or 2 mm from the posterior bony ridge of the lateral femoral condyle (posterior condylar ridge) and 3 to 4 mm posterior (low) from the extended line of the posterolateral corner of the intercondylar ridge at 90° of knee flexion.[24] The center of the posterolateral (PL) bundle footprint was positioned 5 to 8 mm anterior (high) to the edge of the posterior cartilage on an

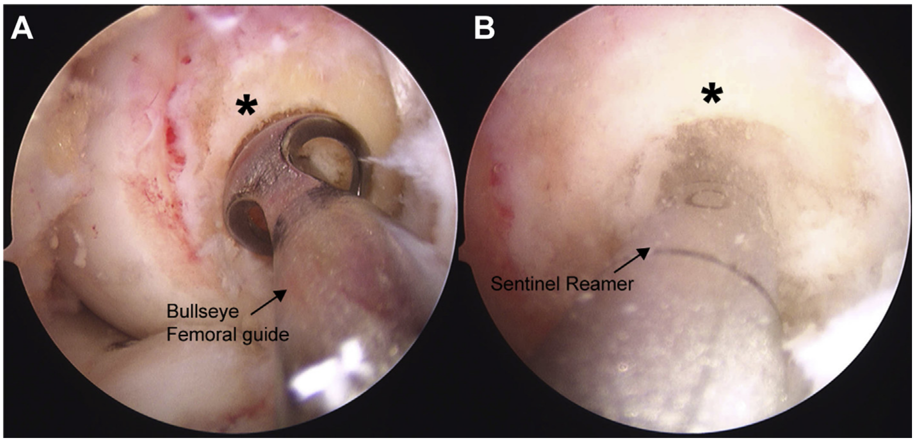

Fig 1. Femoral tunnel drilling using TP technique with Bullseye guide. (A) The Bullseye femoral guide was inserted through the accessory anteromedial portal, and a 2.4-mm guide pin was inserted 2 to 3 mm by tapping through the Bullseye guide at the anatomic center of the ACL footprint. (B) With the knee fully flexed, a Sentinel cannulated reamer was inserted over it and drilled to 27 mm. The asterisks indicate the medial wall of the lateral femoral condyle.

imaginary line perpendicular to the tangent at the lowermost position of the lateral femoral condyle at 90° of knee flexion.[25] Throughout this procedure, 90° of knee flexion was maintained by the assistant. We used a curved Steadman awl (ConMed Linvatec, Largo, FL) to put a mark between the center of the AM and PL femoral footprints, which we assumed to be the anatomic center of the ACL footprint.

Anatomic SB ACL Reconstruction Using TP Technique. A Bullseye femoral guide (ConMed Linvatec) was inserted through the accessory anteromedial portal, and a 2.4-mm guide pin was inserted 2 to 3 mm by tapping through the Bullseye guide at the anatomic center of the ACL footprint. With the knee fully flexed, the guide pin was inserted through the lateral femoral cortex, and a Sentinel cannulated reamer (ConMed Linvatec) was inserted over it and drilled to 27 mm, which allowed a 20-mm-long graft in the femoral tunnel and an EndoButton (Smith & Nephew Endoscopy, Andover, MA) flipping outside the femoral tunnel. A 4.5-mm EndoButton drill bit (Smith & Nephew Endoscopy) was then used to drill through the lateral cortex (Fig 1).

Anatomic SB ACL Reconstruction Using OI Technique. A central midpatellar portal was made at the patellar tendon to insert the RetroConstruction Drill Guide (Arthrex, Naples, FL). The center of the guide tip was placed on the previously marked anatomic center of the ACL footprint. To increase reliability, we used a standard procedure to create the femoral tunnel. The guide angle was set to 110° in the coronal plane and 10° in the axial plane of the distal femur. We drilled the FlipCutter (Arthrex) into the joint through a 1-cm incision that was just superior and posterior to the lateral femoral epicondyle, and we lightly tapped the 7-mm drill sleeve tip into the cortex. The drill was progressed forward with retrograde force to a depth of 27 mm after rotating the blade 90° into the cutting position. The FlipCutter was removed after loosening the blade (Fig 2).

CT Protocol and Measurement

CT scans were performed on all knees after ACL reconstruction with the patient's informed consent. A 64-slice multidetector CT scanner (Brilliance 64; Philips, Cleveland, OH) was used for all examinations. During the examination, the knee was positioned fully extended. After extracting the Digital Imaging and

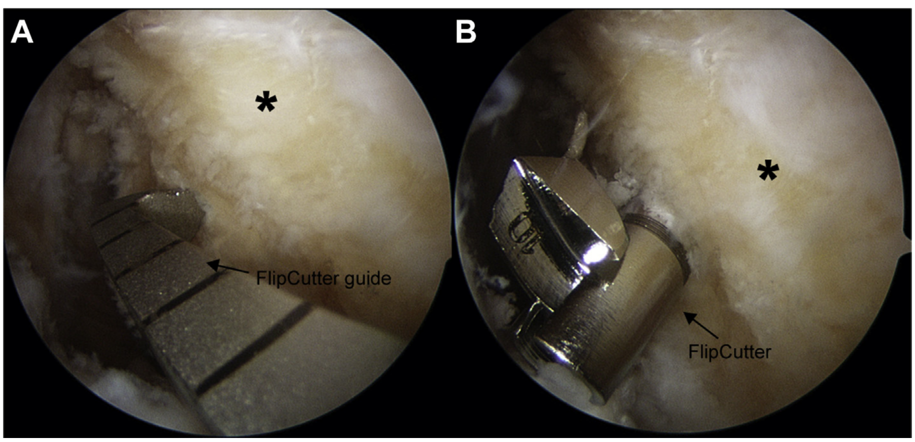

Fig 2. Femoral drilling using OI technique with FlipCutter. (A) The center of the RetroConstruction Drill Guide tip was placed on the previously marked anatomic center of the ACL footprint. (B) The FlipCutter was inserted into the joint and was progressed forward with retrograde force to a depth of 27 mm after rotating the blade 90° into the cutting position. The asterisks indicate the medial wall of the lateral femoral condyle.

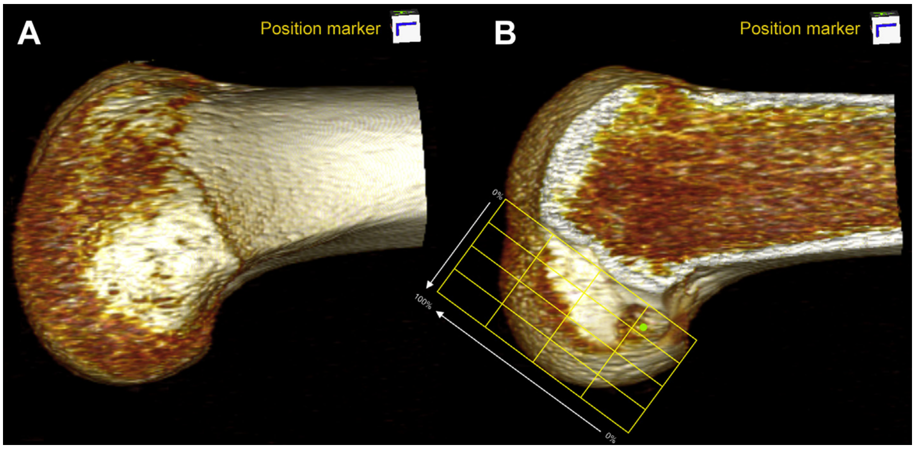

Fig 3. Femoral tunnel position measurement using 3D CT. (A) The distal femur model was positioned horizontally by superimposing the medial and lateral femoral condyles. In that position, the position marker in the OsiriX software was checked. (B) After removal of the medial femoral condyle, the aperture center of the femoral tunnels was presented as the percentage distance from the deepest subchondral contour and the intercondylar notch roof.

Communications in Medicine (DICOM) data from the picture archiving and communication system (PACS) software (Pi View STAR, version 5025; Infinitt, Seoul, South Korea), we imported the data into OsiriX imaging software (version 3.8). OsiriX is free DICOM software that is used widely in clinical and research fields with comparable efficacy and reliability to commercially available software.[26,27]

To measure the femoral tunnel position, DICOM data were imported into OsiriX to create a 3D model of the distal femur. Initially, the distal femur model was positioned horizontally in a strictly lateral position, in which both femoral condyles were superimposed as described by Bernard et al.[28] for the lateral radiograph of the knee.[29] In that position the position marker in the OsiriX software was checked to ensure a strict lateral position after removal of the medial femoral condyle and to increase reliability of the measurements. The aperture centers of the femoral tunnels were pointed and presented as the percentage distance from the deepest subchondral contour and the intercondylar notch roof to the center of the femoral tunnel aperture (Fig 3).[14] 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 by using the multiplanar reconstruction tool of the OsiriX software.[14] We measured the femoral graft bending angle formed by these 3 points. The plane in which the entire length of the femoral tunnel showed the maximum width was selected to measure femoral tunnel length. This plane was assumed to pass through the center of the tunnel. The distance between the centers of the intra- and extra-articular tunnel apertures was measured (Fig 4). We also evaluated posterior wall breakage of the femoral tunnel (Fig 5).

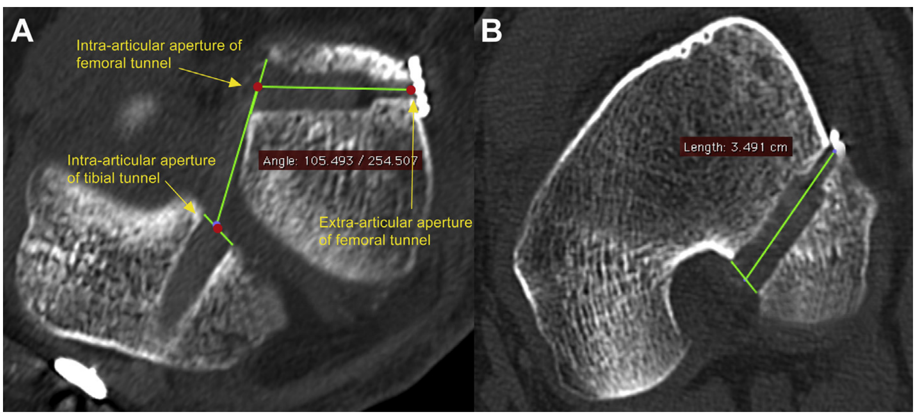

Fig 4. Femoral graft bending angle and femoral tunnel length measurement using 3D CT. The appropriate plane was found by using the multiplanar reconstruction tool of the OsiriX software. (A) The femoral graft bending angle plane, in which the centers of the extra- and intra-articular apertures of the femoral tunnel and the center of the intra-articular aperture of the tibial tunnel were viewed together, was selected. The femoral graft bending angle was defined as the angle formed by these 3 points. (B) The plane in which the entire length of the femoral tunnel showed the maximum width was selected. The distance between the centers of the intra- and extra-articular femoral tunnel apertures was measured.

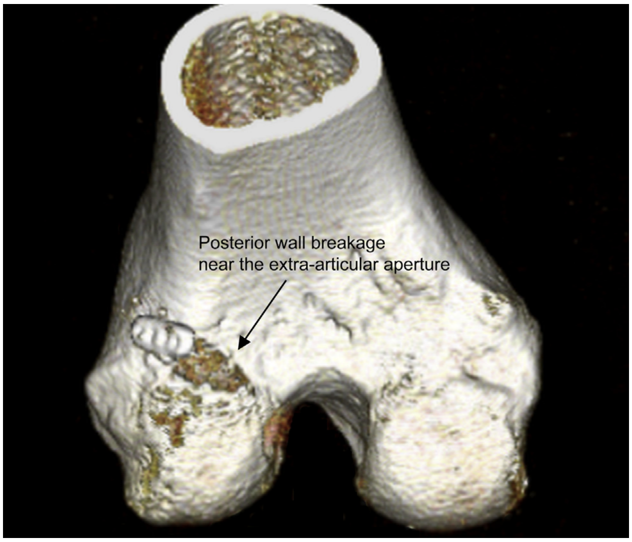

Fig 5. Posterior wall breakage on 3D CT.

Table 2. Results of ICC Value of Each Measurement

	Femoral Tunnel Position		Femoral Graft Bending Angle	Femoral Tunnel Length
	Vertical	Horizontal		
Intertester				
ICC	0.902	0.842	0.847	0.986
Minimum ICC	0.823	0.803	0.824	0.963
Maximum ICC	0.935	0.885	0.889	0.999
Tester 1				
ICC	0.831	0.843	0.809	0.963
Minimum ICC	0.812	0.815	0.801	0.954
Maximum ICC	0.864	0.889	0.864	0.987
Tester 2				
ICC	0.821	0.853	0.852	0.992
Minimum ICC	0.808	0.812	0.821	0.989
Maximum ICC	0.857	0.903	0.908	0.999

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

ICC, intraclass correlation coefficient.

Reliability and Statistical Analysis

The reliability of the measurements was proved in previous studies.[14,20] Two orthopaedic surgeons (independent observers, 1 shoulder surgeon [C.H.O.] and 1 knee surgeon [J.G.K.], who were blinded during measurement) measured the femoral graft bending angle, femoral tunnel length, and femoral tunnel position after development of and agreement with the measurement methods together. They made the measurement twice with an interval of 2 weeks. They were blinded to each other's measurement, as well their own prior measurement. The reliability of the measurements was assessed by examining the intraobserver and interobserver reliability using the intraclass correlation coefficient. The averages of 2 measures were used for analysis. At an α level of .05 and power of 0.8, a post hoc power analysis was performed using the calculated mean and standard deviation for femoral tunnel length, which was the primary outcome variable of this study. This study showed power of 93% for a sample in each group to detect a significant difference in femoral tunnel length between the 2 groups. The results of the 2 groups were compared with a 2-sample *t* test, Pearson χ^2 test, and Fisher exact test for the demographic data, femoral tunnel position, femoral graft bending angle, femoral tunnel length, and posterior wall breakage. Statistical significance was set at $P \leq .05$. Statistical analysis was performed with SAS software (version 9.2; SAS Institute, Cary, NC).

Results

The interobserver reliability and intraobserver reliability ranged from 0.80 to 0.99 (Table 2).

Femoral Tunnel Position

The mean distance of the femoral tunnel position parallel to the Blumensaat line in the TP group was longer than that in the OI group ($P = .005$). The mean femoral tunnel position parallel to the Blumensaat line from the arthroscopic position was shallower in the OI group than in the TP group. However, there was no significant difference in femoral tunnel position perpendicular to the Blumensaat line between the 2 techniques ($P = .10$) (Fig 6).

Femoral Graft Bending Angle, Femoral Tunnel Length, and Posterior Wall Breakage

The mean femoral graft bending angle was significantly more acute in the OI group than the TP group ($P = .02$). The difference in the mean femoral graft bending angle between the TP and OI groups was 6.6°. The mean femoral tunnel length was longer in the OI group than the TP group ($P = .003$). The difference in the mean femoral tunnel length between the TP and OI groups was 3.4 mm. The number of cases with a femoral tunnel length of less than 30 mm was 9 (42.8%) in the TP group and 5 (16.6%) in the OI group ($P = .03$). There were 4 cases with a femoral tunnel length of less than 25 mm in only the TP group. There were 7 cases (33.3%) of posterior wall breakage in the TP group but only 1 case (3.3%) of posterior wall breakage in the OI group ($P = .02$). All data are summarized in Table 3.

Discussion

We found that the OI technique led to a shallower femoral tunnel position in the arthroscopic position, a more acute femoral graft bending angle, and a longer femoral tunnel length than the TP technique after anatomic SB ACL reconstruction. Many studies have compared femoral tunnel position and femoral tunnel geometry between the TP and OI techniques after anatomic SB ACL reconstruction[21-23,30]; however, most of these studies were performed with cadavers or

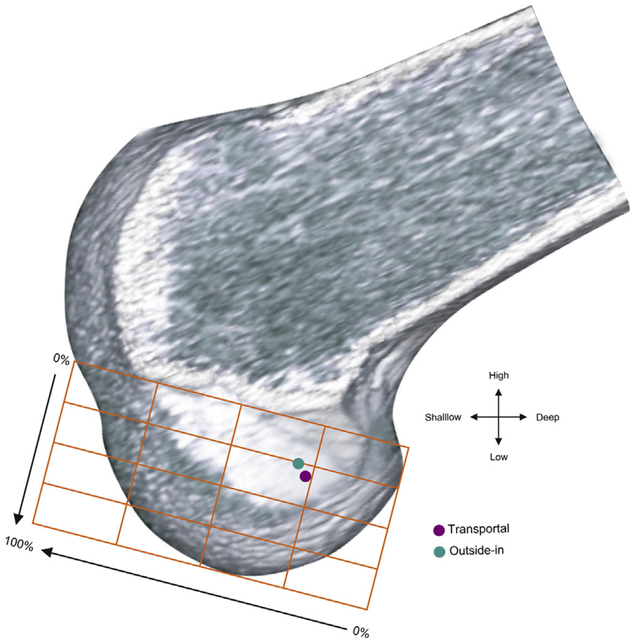

Fig 6. Femoral tunnel position with TP and OI techniques. The femoral tunnel position was shallower with the OI technique than with the TP technique.

simple radiographs, and few studies used CT scans of actual patients (in vivo).[23] To our knowledge, this is the first in vivo 3D CT study evaluating both femoral tunnel position and geometry after anatomic SB ACL reconstruction with the TP and OI techniques.

In our study, the femoral tunnel position was shallower with the OI technique than with the TP technique. The most likely cause of this difference was the mismatch between the aiming center and the reaming center. Kim et al.[13] suggested that the guide tip of the FlipCutter impacting the medial wall of the lateral femoral condyle during OI femoral drilling causes a mismatch between the aimed center and the drilling center. However, we did not evaluate the distance between the femoral tunnel position and the ACL footprint center, so we could not conclude superiority of the accuracy in making the femoral tunnel using each technique. Nonetheless, our results may be of use to surgeons performing anatomic SB ACL reconstruction with the TP or OI technique. Shin et al.[23] compared the femoral tunnel position among transtibial, TP, and OI techniques in an in vivo 3D CT study. They suggested that the femoral tunnel positions (both low and high positions) were not significantly different between the TP and OI techniques. Chang et al.[21] used simple radiographs to compare the coronal femoral tunnel position (low and high positions) between the TP and OI techniques, and they also found no significant difference in the coronal position of the femoral tunnel between the 2 techniques. In contrast, Larson et al.[22] conducted a cadaveric study and found that the mean distance from the tunnel margin to the inferior articular margin (low and high positions) was significantly different between the 2 techniques. However, Kim et al.[13] suggested that the mean position of the AM femoral tunnel was not significantly different between techniques, but the mean position of the PL femoral tunnel after the OI technique was shallower than that of the TP technique after anatomic double-bundle reconstruction. Thus their results were similar to our results. This study may have differed from that of Shin et al. because they measured the femoral tunnel position in the PACS using 3D CT. It would be difficult to place a 3D CT image consistently in the strict lateral position during measurement of the femoral tunnel position in the PACS. However, we used OsiriX software instead of the PACS, and this enabled us to consistently rotate the 3D CT images to the strict lateral position, suggesting that our methods were more reliable.

In this study the mean femoral graft bending angle was more acute with the OI technique than with the TP technique. Similarly, Kim et al.[14] suggested that the mean AM and PL femoral graft bending angles were more acute with the OI technique than with the TP technique after double-bundle ACL reconstruction. The more acute the femoral graft bending angle, the greater the bending stress of the ACL graft at the aperture of the femoral tunnel. This bending stress on the graft at the femoral tunnel aperture is believed to be responsible for graft damage and tunnel enlargement.[15-17,31] Otsubo et al.[17] reported that complete or partial ruptures were observed in 11% of PL grafts at the femoral tunnel aperture in arthroscopic evaluations performed after anatomic double-bundle ACL reconstruction with the TP technique. In this respect, the TP technique might be more advantageous than

Table 3. Comparison of Femoral Tunnel Position, Femoral Graft Bending Angle, and Femoral Tunnel Length Between Groups

	TP Group (n = 21)	OI Group (n = 30)	*P* Value
Femoral tunnel position			
Perpendicular to Blumensaat line, %	32.1 ± 8.0 (16-45)	27.6 ± 10.1 (6-53)	.10
Parallel to Blumensaat line, %	26.7 ± 4.5 (16-35)	31.3 ± 6.0 (16-44)	.005
Femoral graft bending angle, °	107.9 ± 10.0 (88.6-123.1)	101.3 ± 8.2 (79.2-124.1)	.02
Femoral tunnel length, mm	29.6 ± 3.9 (21.2-37.8)	33.0 ± 3.5 (24.6-39.9)	.003
Posterior wall breakage, n	7	1	.02

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

the OI technique. The maximum difference in the femoral graft bending angle between the 2 techniques was 43.9°, although the average difference in the femoral graft bending angle was only 6.6°. Therefore this difference may be clinically significant in the more extreme cases.

In our study the mean femoral tunnel length was significantly longer with the OI technique than with the TP technique. The maximum difference in the femoral tunnel length between the 2 techniques was 18.7 mm, although the mean difference was only 3.4 mm. In a cadaveric study, Lubowitz and Konicek[12] suggested that the mean femoral tunnel length was greater with the OI technique than with the TP technique after SB ACL reconstruction. Chang et al.[21] measured the femoral tunnel length intraoperatively during SB ACL reconstruction and found that the TP group had a significantly greater proportion of knees with a femoral tunnel length of less than 30 mm than did the OI group, although the difference in femoral tunnel length between the 2 techniques was not statistically significant. Our results may have differed from those of Chang et al. because they measured the femoral tunnel length intraoperatively with the use of a depth probe but without the use of CT imaging. Because intraoperative measurement of the femoral tunnel length with a depth probe is probably not as accurate as measurement with a CT image, their results may not have reflected the true femoral tunnel length, especially with the OI technique.[20]

A short femoral tunnel length is one of the disadvantages of the TP technique.[32,33] To prevent this problem with the TP technique, the knee should be flexed maximally because the femoral tunnel length increases as the knee flexion angle increases.[34] A short femoral tunnel can result in reduced graft length in the femoral tunnel when using a suspensory fixation device because of the length of the loop, which could compromise the healing process.[35] Because it is unknown whether the graft length in tunnels of less than 15 mm can be safely used in ACL reconstruction, particularly for humans,[18,35,36] the femoral tunnel length should be greater than 30 mm to make the graft length in the tunnel greater than 15 mm when using a suspensory fixation device. In our study the number of cases with femoral tunnel lengths of less than 30 mm in the TP group (9 cases) was significantly more than that in the OI group (5 cases). Therefore the OI technique would be more advantageous in graft healing than the TP technique when using a suspensory fixation device. In cases of femoral tunnel lengths of less than 30 mm, new adjustable suspensory fixation devices may be beneficial, such as EndoButton Direct (Smith & Nephew) or Tightrope RT (Arthrex), which can fix the graft fully in the tunnel without regard to the length of the femoral tunnel.

Posterior wall breakage is one of the disadvantages of TP techniques. In this study the incidence of posterior wall breakage was 33% with the TP technique. Similar to our results, Kim et al.[14] found that posterior wall breakage developed in 23.8% of cases. However, Chang et al.[21] reported an incidence of only 3% with the TP technique. In their study posterior wall breakage was said to occur when the posterior cortical wall felt soft on intraoperative probing. In probing the femoral tunnel, it appears that they probed only around the femoral tunnel aperture but not near the exit of the femoral tunnel, which could explain their relatively low incidence of posterior wall breakage. Another explanation for our relatively high incidence of posterior wall breakage is the thicker diameter of the femoral tunnel (mean, 8.6 mm) that we made during ACL reconstruction using the TP technique.

Limitations

This study has several limitations. First, this study was retrospective in design. Nonetheless, the data were recorded prospectively because we consistently took 3D CT scans of all patients 3 days after ACL reconstruction. Second, the number of cases was relatively small. In our study the mean femoral tunnel length was 3.4 mm. However, we could not show that this small difference would be clinically meaningful, as well as what the clinically meaningful difference was. Therefore this study possibly would show a high β error according to what the clinically meaningful difference was, although the study showed 93% power to detect a difference in femoral tunnel length, which was the primary outcome variable, between the 2 groups with the given sample sizes. Third, we were not able to report the clinical outcome and follow-up arthroscopic findings because our follow-up period was too short. The mean follow-up period of the OI group was 7.5 months (range, 0.5 to 21 months). Therefore we could not provide evidence that one technique was superior to the other, nor could we report whether the relatively small differences we recorded were clinically significant. Comparing clinical results between the 2 techniques will be performed in our next study. Fourth, we were not able to calibrate the CT scan to have standardized measurements because not all the femurs are the same size among patients and simply importing the data may give false information. However, Kim et al.[27] studied the accuracy and reliability of length measurement on CT with OsiriX software. CT was performed on 14 frozen pig knees without calibration. Kim et al. reported that the mean difference between OsiriX and real measurements, which were made using a digital caliper, were less than 0.1 mm, and maximum differences were less than 0.3 mm. This resolution is regarded as negligible in research involving human joints.[27] Fifth, in this study, 2 independent observers (2 orthopaedic surgeons) measured the variables. However, a radiologist was not involved. Finally, the femoral graft bending angle was evaluated only in the extended knee position. During normal walking or running, midflexion status is more frequent than extension status. Therefore it is doubtful that the femoral graft bending angle measured in the extended position would reflect bending stress during normal walking or running. However, because the tension of the ACL is greatest in the extended knee position,[16,37] we believe that obtaining the 3D CT scan in the extended knee position is the best way to evaluate the graft bending stress. Despite these limitations, ours is the first in vivo study to use 3D CT to compare femoral tunnel position and geometry between 2 different anatomic ACL reconstruction techniques (TP and OI techniques) after SB ACL reconstruction.

Conclusions

The mean femoral tunnel position was significantly shallower with the OI technique than with the TP technique. The OI technique resulted in a more acute femoral graft bending angle, longer femoral tunnel length, and lower incidence of posterior wall breakage than did the TP technique. These results might be helpful for anatomic SB ACL reconstruction using TP and OI techniques.

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